S·A·E JOURNAL

PUBLISHED BY THE SOCIETY OF AUTOMOTIVE ENGINEERS, INC.

William B. Stout, President — David Beecroft, Treasurer

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Vol. 36 — APRIL, 1935 — No. 4

CONTENTS

New S.A.E. Steel Data Embody Wide Engineering Significance— F. P. Gilligan 13

Executives Laud New S.A.E. Standards 16

New Steel Data in Special Pamphlet As Well As in S.A.E. Handbook 18

News of the Society 21

Tractor and Industrial Group Gets Professional-Activity Status 23

Meetings Calendar 24

Transactions Section Begins

Vehicle Design from a Maintenance and Operating Standpoint — (Part 2) — Fred L. Faulkner 117

Flame Temperatures Vary with Knock and Combustion-Chamber Position— Gerald M. Rassweiler and Lloyd Withrow 125

The Winter Operation of Aero Engines— Alan Ferrier 137

The Lubrication Requirements of Automotive Worm Gearing— C. H. Schlesman 147

Main Points in C. C. Minter's Paper Analyzed by Prominent Discussers 159

Transactions Section Ends

Membership Activities 25

What Members Are Doing 26

Amendments to Constitution 27

New Members Qualified 28

Applications Received 28

Notes and Reviews 30

Publication Office, 56th and Chestnut Sts., Philadelphia, Pa.; Editorial and Advertising Departments at the headquarters of the Society, 29 West 39th St., New York, N. Y. Western Advertising Office, Room 2-136 General Motors Bldg., Detroit, Mich.

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New S. A. E. Steel Data Embody Wide Engineering Significance

By F. P. Gilligan

Chairman, Iron and Steel Division,
Standards Committee, Society of Automotive Engineers

IT is now nearly thirty years since a group of automobile engineers, known as the Mechanical Branch of the Association of Licensed Automobile Manufacturers, engaged the late Henry Souther as consulting metallurgist and called into conference several steel mill representatives to discuss the need for chemical specifications for a limited group of steels that would be suitable for the construction of the various automobile parts.

At that time the commercial structural steels were chiefly of the carbon steel type and were quite generally sold on the basis of physical properties in the condition as delivered to the purchaser. Alloy steels were merchandised under trade names and each producer used an analysis that differed slightly but significantly from his competitor's. The art of heat treatment as applied outside the toolroom or blacksmith shop was in its infancy, and amidst the known and unknown variations in the steels used and the frequent absence of pyrometers on furnaces difficult to control, the engineer and the production departments were almost continually in hot water—which may explain why so many shop executives were considered "hard boiled" in those days. Consequently, when the automobile engineer of that day desired to change his source of supply he had reason to hesitate lest his last state be worse than his first.

The steel companies, having considerable ordnance and tool steel experience, recognized the problem that confronted the automobile engineer and willingly cooperated in the development of a group of chemical specifications for both carbon and alloy steels which enabled the engineer to exercise some choice in the type of steel used and in the range of physical properties produced by suitable heat treatment. They also assisted in the preparation of recommended methods of heat treatment.

F. P. Gilligan

Secretary-Treasurer,
The Henry Souther Engineering Co.

That group eventually developed into the S.A.E. Iron and Steel Division, and its first report under that title was published in 1911. It covered eighteen steels, seven carbon and eleven alloy steels. In 1912 the S.A.E. numbering system for steel was adopted, and in 1915 the first physical property charts for S.A.E. steels were published.

It is very doubtful if even the most ardent enthusiast in the group that initiated this standardization work on steels ever dreamed the day would come when, to satisfy the demands of the users of these specifications, over one hundred

chemical compositions would be known as S.A.E. steels, or that the users would extend to practically every field of steel consumption where heat treatment is an essential part of the production process. The same art of heat treatment that brought these steel specifications into existence has promoted their general use and made them a part of the daily language of every metallurgist and steel treater. As a result of this popularity, of their general appropriateness for all types of construction, and convenience of identification they enjoy both national and international recognition.

The last previous extensive revision was made in 1922. Since that time research by both steel user and steel maker has brought forth new steels, as well as modifications in and refinements of many of the long established compositions. A series of heat and corrosion resisting alloys has been added. Advantage has been taken of the results of extensive research in the melting and finishing operations of steel making and a system of grain size control adopted for the purchase of various types of S.A.E. steels. The grain size chart adopted as standard by the S.A.E. was developed by the American Society of Testing Materials, in which work individual members of the S.A.E. Iron and Steel Division, representing users and consumers, participated.

Iron and Steel Division
S.A.E. Standards Committee

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E. W. Upham	Chrysler Corp.
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T. H. Wickenden	International Nickel Co.
Henry Wysor	Bethlehem Steel Co.

Another new feature is the inclusion of a group of specifications for automotive gray iron castings. These specifications pertain to strictly automotive products, and are intended to supplement, not displace, existing gray iron specifications as developed by the American Society for Testing Materials and the American Foundrymen's Association.

By reason of the increasing use of heat treated steel castings, carbon and alloy, of which many types practically duplicate the compositions of S.A.E. wrought steels, the Iron and Steel Division adopted as S.A.E. standard the latest approved specifications of the American Society for Testing Materials, as that Society has thoroughly covered this field and its specifications for steel castings are entirely acceptable in every respect for both automotive and general users.

Likewise, the Iron and Steel Division has adopted as an S.A.E. standard Specification A-47-33 of the American Society for Testing Materials for Malleable Iron Castings, in the development of which automotive interests participated.

This procedure is in conformity with the practice of the Division to avoid entering fields of metallurgical standardization that are being efficiently handled by other groups, but to cooperate with such groups in the adoption of common specifications where practicable.

When the Iron and Steel Division began this revision in April, 1934, it had to give careful consideration to the new conditions established by the adoption of the Steel Code and it therefore arranged for the attendance of a considerable number of representative steel users who were not directly represented on the Iron and Steel Division. Both steel users and steel makers were invited to express themselves freely upon all questions pertaining to S.A.E. steel compositions and their relation to Steel Code practice. Out of such general discussion was developed a plan of action consistent with the long established policy of the Iron and Steel Division—namely, to provide for its membership and the users of its specifications steels that were technically adequate and commercially available.

When there appeared to be need for composition limits not then recognized by the Steel Code, the question was referred to the steel company representatives on the Iron and Steel Division who were participating in the development of the Steel Code for further consideration by the Code authorities. In this way a harmonious plan of mutual consideration and reconsideration developed, and it is believed the specification limits ultimately standardized provide grades of steels which are technically adequate for the great majority of users and which are commercially available. It is recognized that in a limited number of applications closer limitation of certain elements might be necessary to meet the specialized practices of some users, but the Iron and Steel Division considers it unwise to adopt limits that would penalize all users in order to satisfy the special requirements of a few.

The significance of the changes made may be summarized briefly. These specifications now cover the carbon range from 0.05 minimum to 1.05 maximum in the carbon series, with sufficient variation in the manganese and sulfur contents to meet the needs of nearly every type of steel user. The compositions standardized conform to the Steel Code requirements for each type, hence there is no necessity for any user to pay a special price because of non-standard limits.

In the alloy series a greatly increased and diversified list of compositions is provided, including heat resisting and corrosion resisting alloys. For every application the user has a wide choice as to type of alloy steel, range of physical properties, and material cost. No steel maker or alloy producer is

subjected to discrimination. The engineer or designer has only to determine his service stress and other essential requirements, make his selection of acceptable steels, and leave the rest to the purchasing and metallurgical departments. This is in marked contrast with the early days of the automobile industry, when the engineer had to use a different composition every time he changed his source of supply.

The engineer or metallurgist who desires to select his steel upon the basis of physical values may begin with a plain carbon steel with a tensile strength around 45,000 lb. per sq. in. and gradually ascend the scale of strengths to the highest values, to 250,000 lb. per sq. in., or even higher, and have available a choice of two or more compositions every step of the way. Excellent alloy steels are now provided for the heaviest of automotive sections. Hence, the engineer or the metallurgist is not confined to a single type of steel or to a single supplier.

It is well understood at this late day that composition, as measured by the elements covered in these and other chemical specifications, is not synonymous with quality. The elements commonly included in specifications of this character enable the user and the maker to arrive at a common understanding as to the type and grade of steel desired. The particular quality a purchaser requires will depend upon additional factors that cannot be specifically defined in a general specification. In general, it may be stated that the quality the purchaser obtains will depend upon his own and his supplier's knowledge of the specific requirements, reinforced by such inspection requirements as he may impose. Of course, under the Steel Code, the imposition of special quality tests, as for example, the Ehn test as to grain size, or microscopic and macroscopic examinations, etc., necessitates the payment of certain standardized extras. It therefore behooves each steel user to identify and to establish in definite values or terms his particular engineering and metallurgical requirements, keeping in mind that a design which is poorly balanced or provides an inadequate factor of safety usually leads to the application of severe quality standards, with consequent purchasing penalties. Close cooperation with the steel maker will promote a common understanding of the essential facts and help avoid charges for unnecessary extras.

One frequently hears the criticism—"There are too many steels included in the S.A.E. specifications." Looking at the matter from the standpoint of ultimate economy that statement may be true. The Iron and Steel Division is not oblivious to the fact that an automobile, a farm tractor, a Diesel engine, a printing press, or even the latest model of streamlined locomotive and train can be built with but a small fraction of the number of steels covered by these specifications.

The S.A.E. Iron and Steel Division, however, has no mandate to dictate to the steel user just what steel he shall use for his particular application, nor has it any mandate to limit the steel maker as to the compositions he shall make. Its job is to bring the various users and makers of each type or grade to an agreement upon a common chemical specification for that steel. It does require that a steel shall have attained a significant volume of production or be generally recognized as necessary before it is established as an S.A.E. steel. Thus, while these specifications provide 109 steels and alloys, the various compositions for a single steel have been reduced from as many as nine to one.

Each user has his preferred steel compositions and each steel company has its particular group of steels upon which it specializes and endeavors to develop continually in the direction of improved quality. To attempt at this time to reduce substantially the varieties of steels in these specifications would not be desirable standardization. Its effect would be to stifle progress.

Ernest F. Davis

Vice-Chairman, Iron and Steel Division, Standards Committee, Society of Automotive Engineers

According to a prominent steel executive, this is an age of tailor-made steels. Such a state of affairs is not the ideal production schedule a steel maker ordinarily strives for. It is a condition bred by intensive competition arising from subnormal steel consumption and it is working to the advantage of the steel consumer from a quality standpoint. Competition is not now confined to the price field, it is a question of quality and service, hence we have the competition of one steel against another; of one alloy against another, and finally, and most important, of the research facilities of one steel company against the research facilities of its competitor. Out of all this we are destined to have more steels before we have less.

Simplification, if it comes, will require the sympathetic interest and active cooperation of engineers and metallurgists in the steel consuming industries. There will be the need for them to supply precise information on the fundamental requirements of each type of steel as to service and manufacture, to supplement similarly unbiased data on economy of production and uniformity of quality to be provided by the steel maker, more facts and fewer opinions from both groups concerning the advantages and disadvantages of the various strengthening elements, with a general willingness to compromise upon a few steels rather than an insistence upon many.

Such simplification would eliminate unnecessary fashions in tailor-made steels, reduce inventories of makers and users, and in time lead to a substantial decrease in the varieties of steels, with consequent increase in the volume of approved types. Decreasing the varieties and increasing the volume is the usual route toward profits. Profits would not be unwelcome to the steel maker, and they should lead to advantages for the steel consumer.

Executives Laud New S.A.E. Standards

Leading experts in automobile, parts and metal industries interpret economic phases of the S.A.E. steel specifications

W. S. Knudsen

Executive Vice-President, General Motors Corp.

says

"... Sums Up Latest Practices"

THE recent revision of the S.A.E. Iron and Steel Specifications admirably sums up the experience and latest practices of our industry.

While a separate standardization program is carried on as a General Motors activity, national standards are without question necessary for developing broad application and general usage.

Active participation over a period of years in S.A.E. Standardization Work is sufficient evidence that General Motors benefits materially from an engineering and economic standpoint through such cooperation.

"...Producers and Consumers Benefit"

By N. L. Deuble

Metallurgist, Republic Steel Corp.

PRIOR to 1911 when the first S.A.E. analysis ranges were published, practically all steels were purchased by trade names. No correlation had previously been attempted by either consumer or producer. In the early days of the alloy steel industry, these trade names represented certain definite analyses, often arranged in series carrying a number suffix denoting the carbon range. Usually the analyses of these products were not given to the customer, so he had to depend upon the integrity of the producer to furnish satisfactory material. In many cases, the consumer had no facilities to determine chemical analyses and the producer usually inferred that there was something special and mysterious about his product, so that the consumer was afraid if he purchased material from another source his product would suffer.

Heat treating was a fine art wrapped in mystery. There are many legends of the desirable quenching characteristics of certain solutions. Also legends in regard to quenching at certain times; for instance, material would not respond unless quenched by the light of the moon or with the axis of the part toward the North Pole.

The Iron and Steel Division of the S.A.E. has taken this confusion and these superstitions and produced not only acceptable standards of analyses but also recommended heat treatments. Along with these, they have also furnished physical property charts which are a great assistance in guiding the heat treater.

It can be readily seen that this standardization has been a great benefit to both the consumer and producer. It has given the purchaser an opportunity to obtain his products from various sources without undue delay. Imagine the blue prints of some parts carrying four or five trade names, where now it is only necessary to specify an S.A.E. analysis. By being able to purchase from various sources, he has created more competition. As the automotive industry increased in size, this competition became keener. This has forced the producer to improve his quality. The producers could no longer depend on the "special" properties of their trade-name products. By putting the producers on a more competitve basis, they have developed better and cheaper steels. They investigate the customers' requirements and develop new steels.

During the World War there was a demand for a high-tensile steel for crankshafts. For this, a chrome-nickel-molybdenum steel was developed, and this year—after many analyses of this type have been produced and tested—the S.A.E. established a standard for this type. Shortly after the development of the chrome-nickel-molybdenum steels was begun, the nickel-molybdenum steels were investigated in various carbon ranges. The carburizing type was found very satis-

factory for many purposes and was adopted by S.A.E. in 1925. Since then, developments have shown that a modification of this analysis was desirable, so it was changed in 1927 and again in 1935. The 3½ per cent nickel-molybdenum steel followed soon afterwards. This analysis has proved satisfactory and has been added to the S.A.E. standards.

By cooperation of manufacturers and consumers, it has been found that materials slightly outside of the old S.A.E. ranges have given definite advantages from a physical property, manufacturing, or economical standpoint. A number of these types have been added to the standards this year because they warrant recognition. Among these steels are the so-called 1020-90, now S.A.E. X-1020; also the G.M.C. 1300 series, now S.A.E. T-1330. Many steels have been added to the S.A.E. ranges this year. These will tend to eliminate confusion, as they are now purchased on coined S.A.E. numbers, trade names, or customers' specifications. By recognizing these and giving them numbers, standardization results. This standardization has been a benefit to the producers, as it has given them graded carbon ranges with the same alloy contents. It has also given them a definite basis for pricing steels.

In 1922, Messrs. McQuaid and Ehn published their valuable investigation, which indicated that with identical chemical analyses, different physical characteristics resulted. At that time the significance of this development was not appreciated. Since that time a great deal of research has been completed. In 1924, one alloy producer brought out a chart grading the grain size from one to ten. This was the first step toward standardization. This chart was recognized by many plants and adopted as a standard. In 1926, another alloy producer published an Ehn chart, but this time instead of using ten divisions, they used nine. Still later another steel manufacturer came out with an eight division chart. The result of this was confusing. A customer purchasing steel to grain size not only had to specify his grain size range, but also the producer's chart. In 1933, the American Society for Testing Materials adopted a tentative standard chart and also procedure E19-33T. This year the Society of Automotive Engineers adopted the A.S.T.M. standards.

By cooperation of consumers and producers on the Iron and Steel Division of the S.A.E., there have been established sets of standards for purchasing steel which have benefited all steel producers and consumers. In this way, the S.A.E. has been a great asset to the steel industry.

"... Advantage to Parts Makers"

By C. W. Spicer

Vice-President, Spicer Manufacturing Corp.

IT is impossible to state in either few or many words, or to express in dollar terms, the very great advantages which accrue to the parts maker as well as all other representatives of the great steel using community, from S.A.E. Iron and Steel Specifications.

It is hard to say which is the more important (*a*) a common language which we can all talk and understand, and which before never existed, or (*b*) a definite classification covering the smallest number of different analyses which are required for commercial use throughout the range from the lowest cost per pound material, to the more expensive alloy steels which must be capable of providing parts of the highest strength and toughness.

"...Best Ideas of Makers and Users"

By Henry Wysor

Metallurgical Engineer, Bethlehem Steel Co., Inc.

THE economic significance of the S.A.E. steel specifications anticipated many years ago what the Department of Commerce under Herbert Hoover attempted to carry out in standardizing commodities.

The value of such a move can best be judged by the adoption or use of such standards. The S.A.E. analysis standards are now widely accepted in public and private enterprises, many of which are not in any way associated with the automotive industry.

The S.A.E. has not only furnished this widely used method of designating the different types of steels, but, in addition, a great amount of useful data on the behavior of the various grades of steels under different conditions. These data are extremely valuable since they represent the latest and best thoughts of both the user and producer.

Economically, it is better for both user and producer to have as few different grades of steel as possible, provided a sufficient number of standards are set up to cover all applications. The user is assured of greater availability, prompter delivery, and higher quality. The producer, by knowing what to anticipate, can allow himself ample time to replete his stocks and to carry out the various inspections and tests on the steel which in many cases would be impossible if the steel had to be rushed through the various processings in the minimum of time actually required to perform them.

With the knowledge that the 1935 standards contain 102 steel grades against 69 in the 1933 standards, the statement just made regarding the minimum number of grades seems superfluous. Careful study of new types of steel developed and wider application of the S.A.E. steel specifications demanded the judicious elimination of some of the obsolete grades and the inclusion of some new grades which overbalanced in number those that were removed.

All changes were made only after thoughtful study by representative users and producers. The remarkable feature is that so large a committee representing many large industries can function as efficiently as it has. This has been accomplished only through close, and open-minded, cooperation between the users as a group and the producers as a group, all striving to give industry as a whole the benefit of their best thoughts on the matter.

In the new steel specifications will be found a much amplified series of carbon steels not only covering a wider range of carbon but also various combinations of carbon and manganese. By general demand the free-cutting grades have been increased from 2 to 9. A new classification was made to cover the steels carrying 1.60 to 1.90 manganese.

The nickel, nickel-chromium, chrome, chrome-vanadium, tungsten, and silico-manganese classifications remain practically unchanged in number. However, the molybdenum steels have been increased from 4 to 12 grades to cover the demands of the users of this steel, the chrome-molybdenum and nickel-molybdenum types both have been increased to cover their wider application and the nickel-chrome-molybdenum grades have been included. A new classification covering corrosion and heat-resisting alloy steels has been added since these types are becoming more and more popular.

The steel producer through this standardization is enabled to give much better service to the users of steel and both indirectly reap an economical benefit.

New Steel Data in Special Pamphlet

THE completely revised S.A.E. Steel Specifications are now available in pamphlet form at $2.50 per copy to non-members, and at $1.25 per copy to members. Discounts will be given on quantity orders.

These new specifications will be included also in the regular S.A.E. Standards Handbook which is distributed free to members.

Because of the important bearing of the information other than the chemical compositions given in this report, these steel specifications will be furnished only in complete form; individual pages or parts will not be distributed as heretofore. This policy was adopted by the Iron and Steel Division of the Standards Committee because it believed the complete data essential to proper application of the specifications.

The complete steel specifications comprise ten parts as follows:

Part I—General Instructions
- Steel Castings

Part II—Numbering System
- Prefixes

Part III—Chemical Compositions

Part IV—Grain Size Charts

Part V—Sampling, Check Analysis

Part VI—Heat Treatments
- General Instructions
- Regarding Heat Treatments and Physical Properties
- Normalizing and Annealing
- Case Hardening
- Heat Treatments

Part VII—Steel Test Specimens

Part VIII—Definitions, Heat Treating Terms

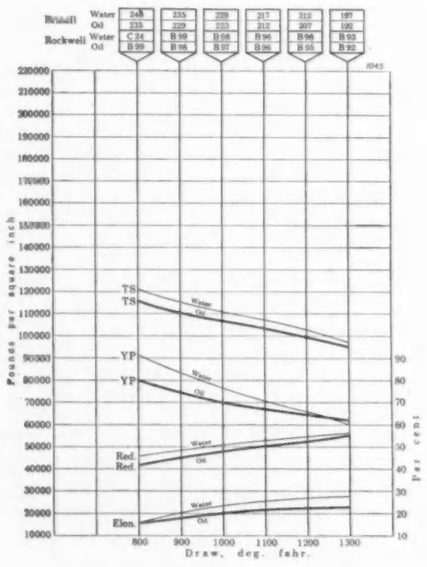
Part IX—Hardness Tests
- Brinell
- Rockwell
- Short

Part X—Physical Properties
- S.A.E. Steels
- Effect of Mass
- Probability Curves

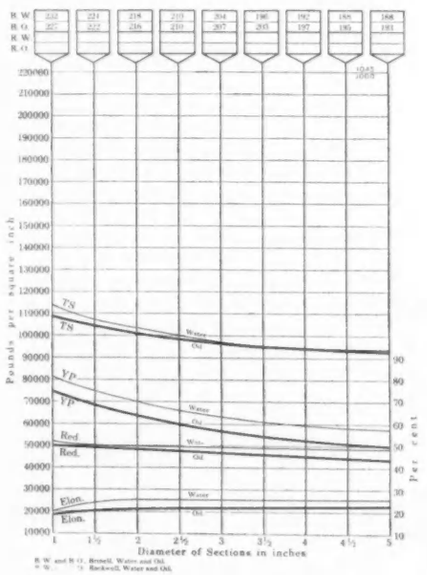
The pamphlet includes also the specifications for malleable iron castings and a newly adopted specification for automotive gray iron castings.

Illustrative of the type of data included in these new specifications is the material in the following charts and tables. From these it will be noted that the new steel compositions are accompanied by supplementary information on heat treatments, by physical property charts showing normal values that may be expected from heat treatments under

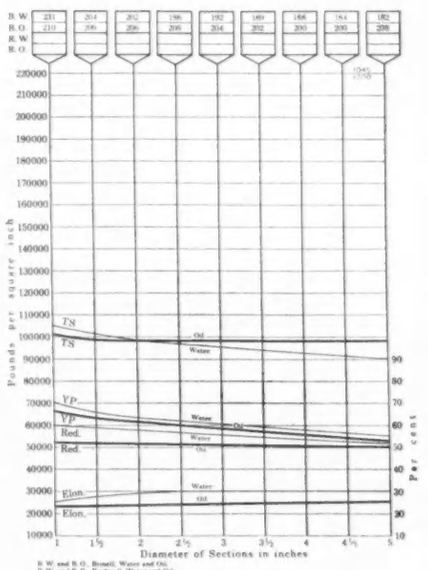
Charts for Typical Carbon Steel (S.A.E. 1045)



Physical Property Chart
Quenched in *water* and in *oil* at 1475 to 1525 deg. fahr.



Effect of Mass Chart
Quenched in *water* and in *oil* at 1500 deg. fahr. Drawn at *1000* deg. fahr.



Effect of Mass Chart
Quenched in *water* and in *oil* at 1500 deg. fahr. Drawn at *1200* deg. fahr.

As Well As in S.A.E. Handbook

normal conditions, and by effect of mass charts illustrating the influence of the size of the piece under treatment on the resultant physical properties. For these purposes of illustration here data have been selected on a typical carbon steel (S.A.E.—1045) and on a typical nickel chromium alloy steel (S.A.E.—3140).

Chemical compositions of the various steels appear on the next page, Page 20.

Heat Treatments

S.A.E. 1045

This is a medium carbon steel intended for the larger sizes of plain carbon steel forgings used in automotive construction, such as crankshafts, starter ring gears, axle and spline shafts. Some hard drawn wire for coiled springs is also made to this specification.

Caution should be used in water quenching this steel in parts of small diameter or thin sections.

Heat Treatment 1045-I

(1) Heat to 1450 to 1550 deg. fahr.
(2) Quench in oil or water depending upon section
(3) Temper to required hardness

Heat Treatment 1045-II

(1) Normalize at 1600 to 1700 deg. fahr.
(2) Reheat to 1475 to 1525 deg. fahr.
(3) Quench in oil or water depending upon section
(4) Temper to required hardness.

S.A.E. 3140

These steels are used for a multitude of heat treated structural parts where good physical properties are required, such as crankshafts, axle shafts, spline shafts, links for drive chains and also for studs, screws and other smaller parts.

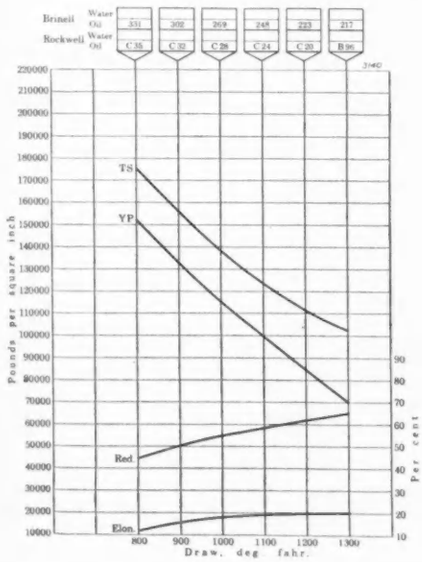
Heat Treatment 3140-I

(1) Heat to 1500 to 1550 deg. fahr.
(2) Quench in oil
(3) Temper to required hardness.

Heat Treatment 3140-II

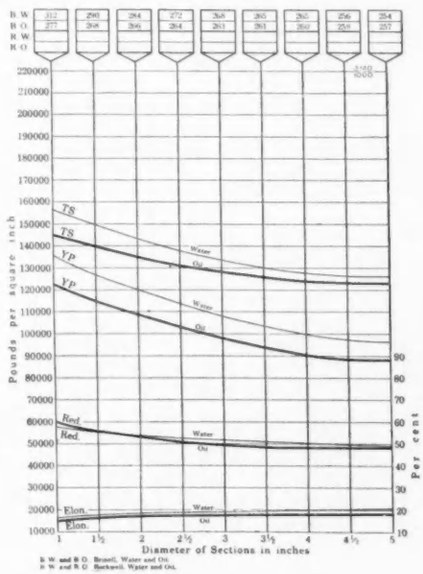
(1) Normalize at 1650 to 1750 deg. fahr.
(2) Heat to 1500 to 1550 deg. fahr.
(3) Quench in oil
(4) Temper to required hardness

Charts for Typical Chromium Nickel Steel (S.A.E. 3140)



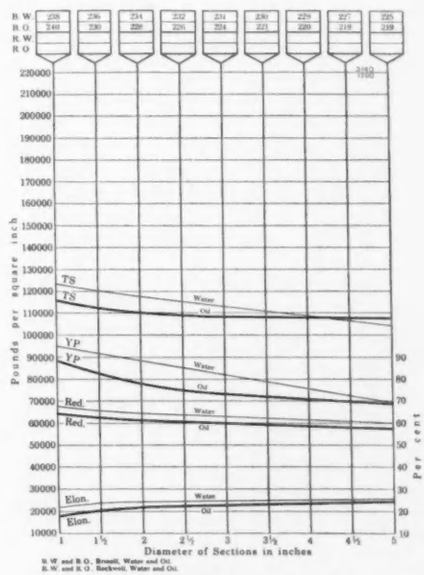
Physical Property Chart

Normalized at 1600 to 1700 deg. fahr. Quenched in *oil* at 1475 to 1525 deg. fahr.



Effect of Mass Chart

Normalized at 1600 to 1700 deg. fahr. Quenched in *water* and in *oil* at 1500 deg. fahr. Drawn at *1000* deg. fahr



Effect of Mass Chart

Normalized at 1600 to 1700 deg. fahr. Quenched in *water* and in *oil* at 1500 deg. fahr. Drawn at *1200* deg. fahr.

Chemical Compositions

CARBON STEELS

S. A. E. No.	Carbon Range	Manganese Range	Phosphorus Max.	Sulfur Max.
1010	0.05–0.15	0.30–0.60	0.045	0.055
1015	0.10–0.20	0.30–0.60	0.045	0.055
X1015	0.10–0.20	0.70–1.00	0.045	0.055
1020	0.15–0.25	0.30–0.60	0.045	0.055
X1020	0.15–0.25	0.70–1.00	0.045	0.055
1025	0.20–0.30	0.30–0.60	0.045	0.055
X1025	0.20–0.30	0.70–1.00	0.045	0.055
1030	0.25–0.35	0.60–0.90	0.045	0.055
1035	0.30–0.40	0.60–0.90	0.045	0.055
1040	0.35–0.45	0.60–0.90	0.045	0.055
X1040	0.35–0.45	0.40–0.70	0.045	0.055
1045	0.40–0.50	0.60–0.90	0.045	0.055
X1045	0.40–0.50	0.40–0.70	0.045	0.055
1050	0.45–0.55	0.60–0.90	0.045	0.055
X1050	0.45–0.55	0.40–0.70	0.045	0.055
1055	0.50–0.60	0.60–0.90	0.040	0.055
X1055	0.50–0.60	0.90–1.20	0.040	0.055
1060	0.55–0.70	0.60–0.90	0.040	0.055
1065	0.60–0.75	0.60–0.90	0.040	0.055
X1065	0.60–0.75	0.90–1.20	0.040	0.055
1070	0.65–0.80	0.60–0.90	0.040	0.055
1075	0.70–0.85	0.60–0.90	0.040	0.055
1080	0.75–0.90	0.60–0.90	0.040	0.055
1085	0.80–0.95	0.60–0.90	0.040	0.055
1090	0.85–1.00	0.60–0.90	0.040	0.055
1095	0.90–1.05	0.25–0.50	0.040	0.055

FREE CUTTING STEELS

S. A. E. No.	Carbon Range	Manganese Range	Phosphorus Range	Sulfur Range
1112	0.08–0.16	0.60–0.90	0.09–0.13	0.10 –0.20
X1112	0.08–0.16	0.60–0.90	0.09–0.13	0.20 –0.30
1115	0.10–0.20	0.70–1.00	0.045 max.	0.075–0.15
1120	0.15–0.25	0.60–0.90	0.045 max.	0.075–0.15
X1314	0.10–0.20	1.00–1.30	0.045 max.	0.075–0.15
X1315	0.10–0.20	1.30–1.60	0.045 max.	0.075–0.15
X1330	0.25–0.35	1.35–1.65	0.045 max.	0.075–0.15
X1335	0.30–0.40	1.35–1.65	0.045 max.	0.075–0.15
X1340	0.35–0.45	1.35–1.65	0.045 max.	0.075–0.15

MANGANESE STEELS[1]

S. A. E. No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulfur, Max.
T1330	0.25–0.35	1.60–1.90	0.040	0.050
T1335	0.30–0.40	1.60–1.90	0.040	0.050
T1340	0.35–0.45	1.60–1.90	0.040	0.050
T1345	0.40–0.50	1.60–1.90	0.040	0.050
T1350	0.45–0.55	1.60–1.90	0.040	0.050

NICKEL STEELS[1]

S. A. E. No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulfur, Max.	Nickel Range
2015	0.10–0.20	0.30–0.60	0.040	0.050	0.40–0.60
2115	0.10–0.20	0.30–0.60	0.040	0.050	1.25–1.75
2315	0.10–0.20	0.30–0.60	0.040	0.050	3.25–3.75
2320	0.15–0.25	0.30–0.60	0.040	0.050	3.25–3.75
2330	0.25–0.35	0.50–0.80	0.040	0.050	3.25–3.75
2335	0.30–0.40	0.50–0.80	0.040	0.050	3.25–3.75
2340	0.35–0.45	0.60–0.90	0.040	0.050	3.25–3.75
2345	0.40–0.50	0.60–0.90	0.040	0.050	3.25–3.75
2350	0.45–0.55	0.60–0.90	0.040	0.050	3.25–3.75
2515	0.10–0.20	0.30–0.60	0.040	0.050	4.75–5.25

NICKEL CHROMIUM STEELS[1]

S. A. E. No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulfur, Max.	Nickel Range	Chromium Range
3115	0.10–0.20	0.30–0.60	0.040	0.050	1.00–1.50	0.45–0.75
3120	0.15–0.25	0.30–0.60	0.040	0.050	1.00–1.50	0.45–0.75
3125	0.20–0.30	0.50–0.80	0.040	0.050	1.00–1.50	0.45–0.75
3130	0.25–0.35	0.50–0.80	0.040	0.050	1.00–1.50	0.45–0.75
3135	0.30–0.40	0.50–0.80	0.040	0.050	1.00–1.50	0.45–0.75
3140	0.35–0.45	0.60–0.90	0.040	0.050	1.00–1.50	0.45–0.75
X3140	0.35–0.45	0.60–0.90	0.040	0.050	1.00–1.50	0.60–0.90
3145	0.40–0.50	0.60–0.90	0.040	0.050	1.00–1.50	0.45–0.75
3150	0.45–0.55	0.60–0.90	0.040	0.050	1.00–1.50	0.45–0.75
3215	0.10–0.20	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3220	0.15–0.25	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3230	0.25–0.35	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3240	0.35–0.45	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3245	0.40–0.50	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3250	0.45–0.55	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3312	max. 0.17	0.30–0.60	0.040	0.050	3.25–3.75	1.25–1.75
3325	0.20–0.30	0.30–0.60	0.040	0.050	3.25–3.75	1.25–1.75
3335	0.30–0.40	0.30–0.60	0.040	0.050	3.25–3.75	1.25–1.75
3340	0.35–0.45	0.30–0.60	0.040	0.050	3.25–3.75	1.25–1.75
3415	0.10–0.20	0.30–0.60	0.040	0.050	2.75–3.25	0.60–0.95
3435	0.30–0.40	0.30–0.60	0.040	0.050	2.75–3.25	0.60–0.95
3450	0.45–0.55	0.30–0.60	0.040	0.050	2.75–3.25	0.60–0.95

[1] Silicon range of all S. A. E. basic open hearth alloy steels shall be 0.15–0.30. For electric and acid open hearth alloy steels, the silicon content shall be 0.15 minimum.

MOLYBDENUM STEELS[1]

S. A. E. No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulfur, Max.	Chromium Range	Nickel Range	Molybdenum Range
4130	0.25–0.35	0.50–0.80	0.040	0.050	0.50–0.80	....	0.15–0.25
X4130	0.25–0.35	0.40–0.60	0.040	0.050	0.80–1.10	....	0.15–0.25
4135	0.30–0.40	0.60–0.90	0.040	0.050	0.80–1.10	....	0.15–0.25
4140	0.35–0.45	0.60–0.90	0.040	0.050	0.80–1.10	....	0.15–0.25
4150	0.45–0.55	0.60–0.90	0.040	0.050	0.80–1.10	....	0.15–0.25
4340	0.35–0.45	0.50–0.80	0.040	0.050	0.50–0.80	1.50–2.00	0.30–0.40
4345	0.40–0.50	0.50–0.80	0.040	0.050	0.60–0.90	1.50–2.00	0.15–0.25
4615	0.10–0.20	0.40–0.70	0.040	0.050	....	1.65–2.00	0.20–0.30
4620	0.15–0.25	0.40–0.70	0.040	0.050	....	1.65–2.00	0.20–0.30
4640	0.35–0.45	0.50–0.80	0.040	0.050	....	1.65–2.00	0.20–0.30
4815	0.10–0.20	0.40–0.60	0.040	0.050	....	3.25–3.75	0.20–0.30
4820	0.15–0.25	0.40–0.60	0.040	0.050	....	3.25–3.75	0.20–0.30

CHROMIUM STEELS[2]

S. A. E. No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulfur, Max.	Chromium Range
5120	0.15–0.25	0.30–0.60	0.040	0.050	0.60–0.90
5140	0.35–0.45	0.60–0.90	0.040	0.050	0.80–1.10
5150	0.45–0.55	0.60–0.90	0.040	0.050	0.80–1.10
52100	0.95–1.10	0.20–0.50	0.030	0.035	1.20–1.50

CHROMIUM VANADIUM STEELS[2]

S. A. E. No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulfur, Max.	Chromium Range	Vanadium	
						Min.	Desired
6115	0.10–0.20	0.30–0.60	0.040	0.050	0.80–1.10	0.15	0.18
6120	0.15–0.25	0.30–0.60	0.040	0.050	0.80–1.10	0.15	0.18
6125	0.20–0.30	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6130	0.25–0.35	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6135	0.30–0.40	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6140	0.35–0.45	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6145	0.40–0.50	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6150	0.45–0.55	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6195	0.90–1.05	0.20–0.45	0.030	0.035	0.80–1.10	0.15	0.18

[2] Silicon range of all S. A. E. basic open hearth alloy steels shall be 0.15–0.30. For electric and acid open hearth alloy steels, the silicon content shall be 0.15 minimum.

TUNGSTEN STEELS[2]

S. A. E. No.	Carbon Range	Manganese, Max.	Phosphorus, Max.	Sulfur, Max.	Chromium Range	Tungsten Range
71360	0.50–0.70	0.30	0.035	0.040	3.00–4.00	12.00–15.00
71660	0.50–0.70	0.30	0.035	0.040	3.00–4.00	15.00–18.00
7260	0.50–0.70	0.30	0.035	0.040	0.50–1.00	1.50– 2.00

SILICON MANGANESE STEELS

S. A. E. No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulfur, Max.	Silicon Range
9255	0.50–0.60	0.60–0.90	0.040	0.050	1.80–2.20
9260	0.55–0.65	0.60–0.90	0.040	0.050	1.80–2.20

CORROSION AND HEAT RESISTING ALLOYS

S. A. E. No.	Carbon, Max.	Manganese, Max.	Silicon, Max.	Phosphorus, Max.	Sulfur, Max.	Chromium Range	Nickel Range
30905	0.08	0.20–0.70	0.75	0.030	0.030	17.00–20.00	8.00–10.00
30915	0.09–0.20	0.20–0.70	0.75	0.030	0.030	17.00–20.00	8.00–10.00
51210	0.12	0.60	0.50	0.030	0.030	11.50–13.00	....
X51410	0.12	0.60	0.50	0.030	0.15–0.50	13.00–15.00	....
51335	0.25–0.40	0.60	0.50	0.030	0.030	12.00–14.00	....
51510	0.12	0.60	0.50	0.030	0.030	14.00–16.00	....
51710	0.12	0.60	0.50	0.030	0.030	16.00–18.00	....

[2] Silicon range of all S. A. E. basic open hearth alloy steels shall be 0.15–0.30. For electric and acid open hearth alloy steels, the silicon content shall be 0.15 minimum.

News of the Society

Standards Bureau In Meeting Spotlight

● **Washington**

The Washington Section staged on March 4 a "National Bureau of Standards Night" for which the speakers were A. N. Finn, Chief of Glass Section, National Bureau of Standards, and Dr. Louis Jordan, Chief of Thermal Metallurgy Section, National Bureau of Standards.

Mr. Finn who is vice-chairman of the American Standards Association, Sectional Committee Z-26 on Safety Glass, discussed the use of this material for glazing automobiles. He cited proposed legislation requiring safety glass windshields on all cars purchased by the government with sidelights on the difficulties of drawing up such a bill that would be technically adequate.

No one type of glass he indicated possesses maximum protective value under all crash conditions. Further, no type of glass can afford complete protection to the occupants of the car, but safety glass does reduce materially the likelihood of injury to passengers in the event of an accident.

To be satisfactory for use in windshields, Mr. Finn said, glass should pass tests designed to determine its resistance to discoloration, humidity, distortion and immersion in boiling water. In addition it should pass tests for resistance to impact with various weights in the shape of balls, darts and shot bags, dropped from known heights. Mr. Finn illustrated some of these tests with motion pictures. Later apparatus was set up and tests were demonstrated with the steel ball and dart using several types of safety glass in foot-square sheets. Much interest, says the report of the meeting, centered around case-hardening glass and the manner in which it crumbles after fracture.

The second speaker, Dr. Jordan, gave a short talk on the elements which have proved useful as alloying agents in steel. He confined his topic to structural steels, stating that in the past five years metallurgists have developed a "philosophy of alloy steels".

He listed as desirable properties in structural steels the following points: deeper hardening; greater resistance to distortion and cracking; resistance to tempering; and greater ductility of given strength.

The meeting was attended by 40 members and guests of the Section.

Arthur Nutt Tells Of World's Air Engines

● **Cleveland**

Arthur Nutt, vice-president in charge of engineering, Wright Aeronautical Corp., Paterson, N. J., gave a "Comparison of American and Foreign Aviation Engines" at the meeting of the Cleveland Section which was attended by 250 members and guests. The sponsor and chairman of the evening was A. T. Colwell, chief engineer, Thompson Products, Inc.

General discussion followed from what turned out to be the record crowd of the year for the Cleveland Section. Ninety guests turned out for the dinner preceding the meeting.

Art in Industry Hailed by Jensen

● **Milwaukee**

Gustav Boerge Jensen, industrial designer, spoke on "Art in Industry" at the Feb. 6 meeting of the Milwaukee Section which was characterized as Ladies' Night and drew an attendance of 85. Mr. Jensen emphasized that we are now at the beginning of what might be called a renaissance—on the threshold of an age of tremendous development and change. In the early days, he said, the brain of the creator and the hand of the worker were one. This period was followed by a machine age in which the engineer tried as best he could to be an artist as well. It is from this era that we are now emerging, he believes.

J. E. Eller, chief engineer, Rolls-Royce, Ltd., Derby, England, was a guest at the meeting, proffering some interesting facts relative to Sir Malcolm Campbell's latest "Bluebird" now at Daytona Beach for speed trials. He pointed out that although the projected area of the new car is nearly double that of its predecessor, its resistance as determined by careful wind-tunnel tests has been reduced 50 per cent.

Harry Horning, past-president of the Society, and Councilor J. B. Fisher who had just returned from Europe enlivened the meeting with some amusing incidents relative to their travels in Mr. Jensen's native Denmark.

Fleet Operation Seen From 6 Points of View

● **Metropolitan**

Following along the general lines of his Annual Meeting paper on the same subject but including considerable new material T. L. Preble presented the "Principles of Fleet Operation" at the March 11 meeting of the Metropolitan Section. Mr. Preble who is supervisor of automotive equipment, Tide Water Oil Co., was the principal speaker, but he was ably seconded by several discussers, including G. W. Batt, comptroller, Dugan Brothers, who expressed executive thoughts about the transportation unit of a large company. William F. Banks, president, Motor Haulage Co., spoke on some of the difficulties involved in general trucking work stressing the need for uniform accounting in arranging their haulage costs.

The factory point of view was represented by B. B. Bachman, past-president of the Society and vice-president of engineering, the Autocar Co., and Thomas C. Huxley, Jr., vice-president, Diamond T Motor Car Co. T. C. Smith, vice-chairman for transportation and maintenance of the Section and supervisor of motor-vehicles and construction apparatus, American Telephone and Telegraph Co., presided at the meeting. Clinton Brettell, superintendent of garages, R. H. Macy & Co., who assisted in arranging the meeting, had charge of the discussion.

F. M. Van Deventer, Cities Service Co., gave a timely summarization of data dealing with "Carbon Monoxide in Moving Vehicles."

Mr. Van Deventer made it clear that many serious motor-vehicle accidents occur as a result of carbon monoxide fumes inside moving vehicles. These accidents, he showed, are not alone a menace to those who ride in the vehicles, many of whom have been killed by the fumes, but also to pedestrians and to other highway users because the fumes slow the reactions of the driver and sometimes render him unconscious so that the vehicle runs wild. Over-rich mixtures, leaky exhaust lines and leaks in vehicle bodies or cabs are the chief causes of such conditions and should be given consideration by all who are in position to prevent such faults. It was shown that even when those using the vehicle producing the deadly fumes are not affected, those who ride in vehicles following them may be, and the larger the vehicle the more potent this menace is likely to be.

The meeting was attended by 240 members and guests with 139 attending the dinner which preceded.

Economical Trucking Described by Schon

● **Chicago**

The importance of selecting the right type of chassis for the work to be done was emphasized by Pierre Schon, transportation engineer, General Motors Truck Co., who presented a paper on "Economical Operation of Motor Trucks" at the March 5 meeting of the Chicago Section. Fred L. Faulkner, automotive engineer, Armour & Co., was chairman of the meeting.

In his paper, Mr. Schon covered the effect on operating cost if poor judgment has been applied in selecting a suitable vehicle. He extended this point with a discussion of the transportation engineering factors which must receive consideration—this phase of the paper being illustrated profusely with slides. The second section of his paper dealt with truck operating costs including a brief analysis of manufacturers' contributions to the lowering of operating expenses and what operators can do to hold operating and maintenance expenses to more economical limits.

The third section covered trends in design from the standpoints of appearance, carrying capacity, performance ability and a more economical operation, including comment upon and analysis of progress made with Diesel engines and the prospects of using cheaper fuels.

The general discussion which followed Mr. Schon's paper revolved principally around its Diesel features. Led by Mr. Faulkner, discussers were: Carl C. Hinkley, Buda Co.; Leo Huff, Pure Oil Co.; and E. W. Lager, Swift & Co.

Vice-Chairman Robert T. Hendrickson presided over a business meeting in the absence of Chairman R. E. Wilkin. It was reported that the Safety Program Coordination Committee provided for at the last meeting of the Section was making progress and that a further report would be made at the next Section meeting.

Carbureted Fuel Oil Evaluated by Jacoby

● **Syracuse**

Carbureted fuel oil may take the place of gasoline as the motor fuel of the future, according to E. R. Jacoby, chief engineer, Continental Motors Corp., who was the speaker at the Feb. 4 meeting of the Syracuse Section to which members of the Technology Club of Syracuse and affiliated societies were invited.

Diesel engines Mr. Jacoby indicated will become increasingly useful in fields where 150 hp. and more is necessary. Their limitations are, he continued, that they can burn only one type of fuel and work most efficiently under a constant load at constant speed.

On the contrary, he said, carbureted fuel oil engines can be fed almost anything that will burn in a given length of time, can operate efficiently at various speeds and under various loads and are almost identical with conventional gasoline engines.

He illustrated with charts the efficiency of such fuels as butane, gasoline, kerosene, fuel oil and natural gas in an engine originally designed for gasoline. Of 32 fuels which have been tried in such tests, he said, 13 were found satisfactory.

The meeting at which Mr. Jacoby spoke was held on the roof garden of the Onondaga Hotel and was attended by 180 members and guests of the section. There were 14 at the dinner preceding the meeting.

Winchester Presents Eastern Travel Talk

● **Baltimore**

J. F. Winchester, manager, general automotive department, Standard Oil Co. of New Jersey, was the speaker at the March 7 meeting of the Baltimore Section. Mr. Winchester's talk was a travelogue on the general subject of "What the Eastern Hemisphere Really Looks Like". For nearly two hours he held an audience of 190 members and guests while he spoke of his recent tour of the Far East which had as its focal point Kurkuk in Irak where his company was participating in the construction of a 600-mile pipe line across and under the Syrian Desert. Mr. Winchester showed several hundred feet of motion pictures taken by himself on the trip.

Maintenance in February

The Feb. 7 meeting of the Baltimore Section had as its speaker A. F. MacDonald, operating manager of the Blue Ridge Transportation Co., who talked on "How to Cut Maintenance Costs," basing his presentation on experience with 175 buses in daily service in five States.

Seventy-one members and guests attended the meeting which was preceded by a dinner attended by 56.

Two Metals Talks At Joint Meeting

● **Dayton**

Metal was king at the Feb. 12 meeting of the Dayton Section at which the speakers were Robert Weber, National Cash Register Co., and E. V. Crane of the E. W. Bliss Co., New York. The meeting was held jointly with the Dayton Section of the American Society for Metals. The chairman of the latter organization introduced Mr. Weber who gave a talk on "The Structural Characteristics of High Carbon Tool Steels", illustrated with slides.

The second speaker, Mr. Crane, described "Sheet Metal Blanking and Deep-Drawing Dies and Their Correlation".

The meeting was attended by approximately 140 persons representing the two Sections. The S.A.E. dinner preceding the meeting was attended by 14.

Ford Subjects Fill Program

● **So. California**

George R. Hill of the Ford Motor Company's Long Beach Branch described Johansson Gage Blocks at the Feb. 8 meeting of the Southern California Section. Al Lang of the same organization gave some of the details of the organization of world-wide standardized service by the Ford Motor Co. The talks were followed by showing of the motion picture **"A Rhapsody in** Steel" which views department by department the workings of the Ford Plant at River Rouge.

R. M. Mock of the Fokker Aircraft Co. had as his guests at the meeting, A. Nischwitz and H. C. VanMeerten of the Fokker Aircraft Co. in Holland, Dr. A. Van der Neut of the Dutch Research Institute for Aeronautics and H. Franse of the Royal Dutch Airlines (K.L.M.).

Several long time members of the Section who had not attended recent meetings were present, bringing the total attendance to 107 with 85 at the dinner which preceded the meeting.

Discussion of the talks was contributed by C. T. Austin, Lockheed Aircraft Corp.; C. H. Jacobsen, Dept. of Water & Power; C. Cottle, Board of Education; and George Yates, Yates Manufacturing Co.

Brake Specialists Draw a Big Crowd

● **Philadelphia**

One of the most interesting meetings of the season in Philadelphia was the Power Brake Symposium held on March 13, which was attended by over 125 members and guests. Two specialists were featured—Stephen Johnson, Jr., chief engineer, Bendix-Westinghouse, on Air Brakes, and Henry D. Hukill, technical supervisor, Brake Division of Bendix Products, on Vacuum Brakes. B. B. Bachman, past-president of the Society, presided at the technical session in his own inimitable fashion.

Mr. Hukill took up in detail the features of vacuum power brakes for truck, tractor-trailer, and combination units, giving much information concerning fundamental requirements of each type of brake application. The simplest type of vacuum installation is the atmospheric suspended type but its use is restricted to single unit vehicles of medium weight and is never recommended for trailers.

The vacuum suspended type of power brake has the widest application and has been developed in a variety of combinations to suit every requirement of heavy duty vehicle operation. The present trend, according to the speaker, is toward increased percentage of power in brake application, usually 70 to 80 per cent, the remainder being physical effort.

Among the special combination units described by Mr. Hukill were the synchronizer valve for trailer control; hydraulic hook-up; the reactionary type of power cylinder so arranged that physical pedal effort and power cylinder force bear a definite relation, usually 1 to 3; vacuum braked trailers behind air braked tractors by the use of the pneumatic relay valve; and many other combinations of primary braking systems.

A recent development is the special continuous duty rotary vacuum pump which is intended for Diesel powered vehicles, aviation, marine, and industrial units. It is designed for continuous duty at 3,000 r.p.m. and at this speed has a displacement of 7 cu. ft. of free air per min. Its normal balancing point is 28½ in. vacuum.

In summarizing, the author stated that in his opinion the vacuum power brake meets all the requirements of an ideal brake for all sizes and all types of commercial units.

Stephen Johnson, Jr., developed his paper around the recent improvements in air braking systems. Among these developments he included the following: compressors having sliding pistons rather than rotary valves, higher speeds and water-cooled heads; introduction of a three-cylinder compressor having twice the displacement of the standard units without increasing its weight or size materially.

Other developments are: use of a relay valve for long wheelbase chassis; relay emergency valve for use with trailers; hand operated valve for control of trailers on down grades. Mr. Johnson also touched on the automatic emergency equipment for setting the brakes in case of accident to the system. Several interesting auxiliary devices are being used by some operators. These include the air operated stop light switch which functions when the pressure reaches 5 lb. per sq. in.; and the low pressure indicator—buzzer or electric light—which functions when the pressure in the air brake system drops below 50 lb.

In discussion, Mr. Bachman commented on the fact that while the vacuum system permits mechanical application of braking effort, the air system does not. This is an inherent difference in the two systems, but Mr. Bachman thinks that the trend is definitely to complete power control.

Among those participating in a very spirited, thought-provoking discussion were J. P. Stewart, F. L. Creager, T. C. Fraser, J. B. Franks, Jr., Adolph Gelpke. E. F. Lowe, S.A.E. assistant general manager, visited with the Section and was introduced at the opening of the meeting.

Discussion brought out that the power brake manufacturers are constantly on the job working on the simplification of existing systems as well as the development of new units aimed at safer operation and lower maintenance.

Society Cooperates In Safety Program

The general Society was one of the cooperating organizations at the Sixth Annual Greater New York Safety Conference held at the Pennsylvania Hotel, New York City, on March 5 to 7. Individual members of the Society had a prominent part in several sessions. A paper concerning "The Automobile—Carefully Made and Carelessly Used," by Paul G. Hoffman, president, The Studebaker Corp. and chairman of the Street Traffic Committee of the Automobile Manufacturers Association was read by Norman G. Shidle, executive editor of the S.A.E. JOURNAL at a session on "The Key to Progress."

At the aeronautical session, the chairman was Edward P. Warner, past-president of the Society and editor of *Aviation*, who functioned in this case as chairman of the Advisory Committee for Aeronautics of the National Safety Council.

J. F. Winchester, manager, general automotive department, Standard Oil Co. of New Jer-

(Continued on page 24)

Tractor and Industrial Group Gets Professional-Activity Status

SWEPT into being by a revived wave of enthusiasm for the possibilities of tractor and industrial power engineering guided through S.A.E. channels, the tenth professional activity of the Society was authorized by action of the S.A.E. Council, meeting in Detroit, March 14.

The new activity, to be known as the Tractor and Industrial Power Equipment Engineering Activity, is an outgrowth of the work of the Tractor and Industrial Power Equipment Committee which in itself was the result of an insistent demand for such a committee which developed at the International Automotive Engineering Congress, sponsored by the S.A.E. in Chicago, September, 1933.

With the authorization of activity status for the tractor and industrial power groups, the Council confirmed C. G. Krieger, agricultural engineer, Ethyl Gasoline Corp., as vice-president representing the new activity. A. W. Lavers, chief engineer, Minneapolis-Moline Power Implement Co., was confirmed as vice-chairman of the Tractor and Industrial Power Equipment Activity Committee.

A petition requesting establishment of the activity was presented to the S.A.E. Council under date of Jan. 31, by a subcommittee of which A. W. Lavers was chairman and the other members were: Elmer McCormick, chief engineer, John Deere Tractor Co.; C. E. Frudden, chief engineer, Allis-Chalmers Mfg. Co., and C. G. Krieger. The petition reviewed the events leading up to the formation of the new activity. When the Tractor and Industrial Power Equipment Committee was organized early in 1934, it organized a national meeting held in Milwaukee on April 18 and 19, 1934. A turn-out of 240 men at this meeting demonstrated beyond question that tractor engineers as a group were worthy of a place in the S.A.E.

Vice-President for New Activity

C. G. Krieger, agricultural engineer, Ethyl Gasoline Corp., receives congratulations on his confirmation as vice-president of the newly created Tractor and Industrial Power Equipment Engineering Activity of the Society. As chairman of the Tractor and Industrial Power Equipment Committee of the Society Mr. Krieger has given yeoman service to the cause of the S.A.E. group interested in tractor and industrial power topics

sun. A second national meeting was held in Chicago on December 5 and 6, 1934, immediately following the Farm Power and Machinery Division of the American Society of Agricultural Engineers. This meeting drew 400 men and resulted in a unanimous vote to petition the S.A.E. Council for the creation of a professional activity to include tractor and industrial power equipment men.

With the petition also was presented overwhelming evidence that the tractor and power industries would give their earnest support to such an activity if it were created. With the petition also came a complete tentative committee organization which awaited only the approval of the S.A.E. Council to put the activity into operation in every one of the usual S.A.E. channels. The personnel of these committees was confirmed by the Council at its March 14 meeting. The committee organization is listed at the left.

Tractor and Industrial Power Equipment Activity Committee

C. G. Krieger, *Chairman*
A. W. Lavers, *Vice-Chairman*

D. P. Barnard
R. C. Chesnutt
A. T. Colwell
J. M. Davies
John Erskine
Paul W. Eells
O. E. Eggen
J. B. Fisher
C. E. Frudden
R. B. Gray
Elmer McCormick
A. F. Milbrath
C. W. Smith
K. D. Smith
L. B. Sperry

Tractor and Industrial Power Equipment Membership Committee

John Erskine, *Chairman*

Paul W. Eells
A. F. Milbrath
J. B. Fisher

Tractor and Industrial Power Equipment Meetings Committee

Elmer McCormick, *Chairman*

C. E. Frudden
John Erskine
A. W. Lavers
Paul W. Eells
C. G. Krieger

sey, was chairman of a session on the commercial vehicle at which David Beecroft, past-president of the Society, and manager of the New York office of Bendix Aviation Corp., discussed the influence of brakes and skids on safety and motor-vehicle operation.

Edwards Speaks To Colorado Group

● **Denver**

James A. Edwards, president and chief engineer, Jesco Lubricants Co., North Kansas City, Mo., addressed a meeting of the S.A.E. Club of Colorado in Denver on Feb. 11. Mr. Edwards discussed the highly specialized engineering and development work being done in the lubricants field and some of the results obtained.

The meeting was held in the plant of the MotoRoyal Oil Co. with which Dean M. Gillespie, president of the Club, is connected. The meeting gave a vote of thanks to Mr. Gillespie for furnishing the meeting place and a Dutch lunch.

S.A.E. Members Invited To Join English Party

Members of the S.A.E. who plan to be in England during the period covered by the dates May 29 to June 1 of this Spring have been invited by the Institution of Automobile Engineers to join with members of the I.A.E. and the French Société des Ingenieurs de l'Automobile in a combined Institution Summer Visit.

As the S.A.E. Journal went to press, details became available of Council authorization of the new Tractor and Industrial Power Equipment Engineering Activity of the Society. In order to include news of this important development in this issue of the JOURNAL it was necessary to leave out a few accounts of Section meetings. These will be published in the next issue of the JOURNAL.

The program has been arranged to begin at Birmingham with a visit to the Austin Works followed by optional visits to several manufacturers in Coventry. On the same evening there will be a banquet at the Welcome Hotel. The party will remain overnight at Stratford and the next day will travel by road to Oxford where it will visit the Morris Works, returning to London in time for dinner. The last day will be devoted to works visits or sightseeing in the London area.

Brian G. Robbins, secretary of the Institution of Automobile Engineers, has informed S.A.E. headquarters in New York that details of the itinerary, transportation charges and hotel accommodations will be available shortly. S.A.E. members interested in participating in this program may communicate with the S.A.E. office in New York from which the details will be forwarded to them as soon as available.

Drake Reports On Detroit Meeting

● **Oregon**

Harley Drake, chairman of the Oregon Section, gave a comprehensive report of what happened at the last Annual Meeting of the Society, as a feature of the Feb. 8 meeting of his Section. Mr. Drake, who is superintendent of automotive equipment for the Portland Gas & Coke Co., pointed out that it was the first time that the Oregon Section had official representation at an Annual Meeting and explained the plan by which such representation will be guaranteed in the future.

H. W. Roberts, Roberts Motor Co., who attended the National Automobile Dealers Association convention in Detroit, as well as the Annual Meeting, gave some of the high spots of the N.A.D.A. convention.

Airlines Subject Of Littlewood's Talk

● **St. Louis**

William Littlewood, chief engineer, American Airlines, Inc., was the speaker of the Feb. 22 meeting of the St. Louis Section held at the Gatesworth Hotel. Taking as his subject "Airline Engineering and Maintenance" he showed several motion pictures of American Airline operations with a running commentary on the material shown. The meeting was attended by 70 with 49 at the dinner preceding.

Meetings Calendar

S.A.E. 30th Anniversary Summer Meeting

The Greenbrier, White Sulphur Springs, W. Va., June 16-21, inclusive.

Baltimore—April 10

Engineers Club; dinner 6:30 P. M. Symposium on Behavior of Fuels—speakers from the National Bureau of Standards. Motion pictures of the Uniontown Tests will also be shown.

Buffalo—April 9

Hotel Statler; dinner 6:30 P. M. Hydrogen Brazing—C. L. West, Electric Furnace Co.

Canadian—April 17

Royal York Hotel, Toronto; dinner 7:00 P. M.

Chicago—April 2

Hamilton Club; dinner 6:30 P. M. The Development of Aircraft Transportation—P. A. Wright, assistant to the president, United Air Lines. The Acoustics of Aircraft—R. F. Norris, director acoustical research, C. F. Burgess Laboratories, Inc. An address will also be given by Jack Night, of the United Air Lines, the subject of which has not as yet been announced.

Cleveland—April 15

Cleveland Club; dinner 6:30 P. M. Annual "Father and Son" Meeting of the Students—speaker Alex Taub, development engineer, Chevrolet Motor Co.

Dayton—April 11

Dayton Engineers Club; dinner 6:30 P. M. Quantitative Spectro Chemical Analysis of Materials—Dr. E. J. Martin, electrical engineer, General Motors Research Laboratories.

Detroit—April 15

Book-Cadillac Hotel; dinner 6:30 P. M. Body and Aeronautic Meeting.

Indiana—April 11

The Athenaeum, Indianapolis; dinner 6:30 P. M. Piston Ring Problems of Diesel Engines—Harry M. Bramberry, engineer, Perfect Circle Co.

Metropolitan—April 8

The Roger Smith, New York City; dinner 6:30 P. M. Lighter-Than-Air Craft—Lieut.-Comm. C. E. Rosendahl, U.S.N.

Milwaukee—April 3

Milwaukee Athletic Club; dinner 6:30 P. M.

Northern California—April 4

Engineers' Club, San Francisco; dinner 6:30 P. M. 30th Anniversary Meeting—The Possibilities of the Automobile—William B. Stout, president, S.A.E. Nine S.A.E. Power Plants—John A. C. Warner, general manager, S.A.E.

Northwest—April 12

New Washington Hotel, Seattle; dinner 6:30 P. M. 30th Anniversary Meeting of the Section—The Possibilities of the Automobile—William B. Stout, president of the S.A.E. Nine S.A.E. Power Plants—John A. C. Warner, general manager of the S.A.E.

Oregon—April 10

Multnomah Hotel, Portland; dinner 6:30 P. M. The Possibilities of the Automobile—William B. Stout, president of the S.A.E. Nine S.A.E. Power Plants—John A. C. Warner, general manager of the S.A.E.

Philadelphia—April 10

Philadelphia Auto Trade Association; dinner 6:30 P. M.

Pittsburgh—April 2

Pittsburgh Athletic Association; dinner 6:30 P. M.

Southern California—March 29

Elks Club, Los Angeles; dinner 6:30 P. M. The Possibilities of the Automobile—William B. Stout, president of the S.A.E. Nine S.A.E. Power Plants—John A. C. Warner, general manager of the S.A.E.

Washington—April 1

University Club, Washington, D. C.; dinner 6:30 P. M. Future of the Autogiro for the Private Flyer—Agnew E. Larsen, Pitcairn Autogiro Co. New Plane Development for the Private Flyer—E. T. Brownell, Bureau of Air Commerce, U. S. Department of Commerce.

Vehicle Design from a Maintenance and Operating Standpoint

Fred L. Faulkner
Automotive Engineer, Armour & Co.

Part 2

IN reviewing the last year's work of the Transportation and Maintenance Group Subcommittee on Motor-Vehicle Design from the operation and maintenance standpoint, permit me to cover briefly its objectives and accomplishments. Part 1 of this paper[1], which covered a study of items about a motor vehicle which were causing the operating personnel a great deal of concern, was presented at the 1934 Semi-Annual Meeting. Many of these items pertain to the servicing of the vehicle, driver's comfort, accessibility and safety. It was pointed out at that time that there was a very grave need for definite standardization on those items which did not enter into the fundamental design of the vehicle.

I am pleased to report that several items which were called to the manufacturers' attention in Part 1 have either been corrected, improved or incorporated into their design, and I have received assurance on the part of other manufacturers that from time to time many of these items will be brought into line with standards recommended. I take this opportunity, on the part of the operators and our Committee, to thank the manufacturers for their whole-hearted support in this movement and for their very willing cooperation in supplying the necessary data to further these studies. I have been asked many times why certain other phases of the design problem were not considered, and I must repeat that it was not the purpose of our Committee to investigate the merit of the design except from the service standpoint. We are interested wholly in obtaining a motor vehicle that will provide transportation in the most economical manner.

In reviewing the wishes of the Committee, I found that there were several troublesome matters that would stand further investigation that were not touched upon in Part 1. These items, however, appear to be those about which the least seems to be known either on the part of the individual operator or the manufacturers' engineers. The majority of these items fall in the accessory classification as follows: Carburetors and manifolds, batteries, starters, generators, ignition coils, power brakes and trailer couplings. In addition, the most perplexing problem that seems to be confronting the operator is the subject of motor-truck ratings.

In our study of the foregoing subject, we set out first to find what the field offered, what the manufacturers were using on various models and why. The first two phases of the subject were relatively easy; but, when it came to determining why certain pieces of equipment were used by a given manufacturer, the problem became extremely complex. I will not attempt to answer these questions, but will show by compiled data the wide range of inconsistencies that exists among the motor-vehicle manufacturers. I have elected to discuss in Part 2 the subject of the Electrical group and the Motor-Truck Rating.

The Storage Battery

We have been given by the Society two revised standards for determining storage-battery performance. First, the number of minutes a battery will deliver 300 amp. continuously to an average final voltage of 1 volt per cell at a battery temperature of 0 deg. fahr. Second, the capacity in ampere hours when discharged at the 20-hr. rate to a final voltage of 1.75 volts per cell at a temperature of 80 deg. fahr. See Fig. 1.

The foregoing standards of ability indicate the minimum performance which is acceptable to the Society. Further, batteries have been classified with characteristics determined from the foregoing statements into groups, designating S.A.E. battery numbers. All references made herein to batteries will be designated by the S.A.E. battery number. In checking through the offerings of the battery manufacturers, I find that some manufacturers will build as many as six different batteries that will qualify under one S.A.E. battery number. The

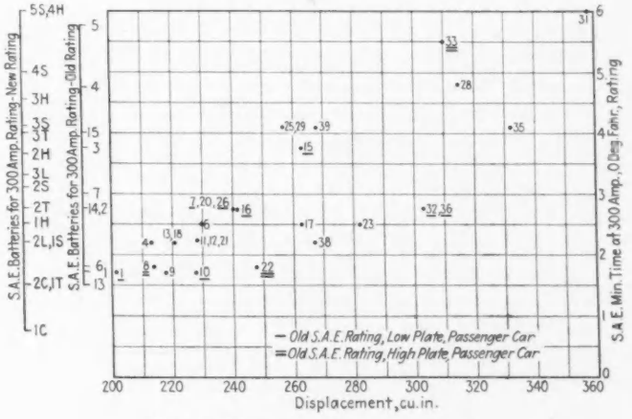


Fig. 1—Data on Storage Batteries

[This paper was presented at the Annual Meeting of the Society, Detroit, Jan. 14, 1935.]

[1] See S.A.E. JOURNAL, September, 1934, p. 311.

Summary

THE Subcommittee on Motor-Vehicle Design from the operation and maintenance standpoint was instructed to continue its studies and prepare a short summary for the 1935 Annual Meeting.

In discussing the possible subject matter with the Committee, so many phases of this subject were questioned that it was impossible in a short space of time to give them full consideration in time for this presentation. I have therefore limited the report to cover mainly the electrical group and the highly controversial subject of motor-truck ratings.

The largest number of complaints and the most severe criticisms on the electrical group come from fleet operators in the so-called low-temperature area. Winter starting-difficulties are prevalent, not only on account of inadequate storage batteries and starting motors but inefficient generators as well. Likewise, this problem is all tied in with the much discussed problem of winter grades of crankcase lubricating oil.

I have not attempted to define where the starter-battery difficulty stops and the lubrication problem begins. However, I am of the opinion that if engine design were improved to the point where 20-W oils could be used economically in all makes of motor-vehicles, our winter starting-difficulties would be minimized.

I have set up data showing the inconsistency that exists between the generator-battery starter-combination as applied by various manufacturers. It is obvious that the winter starting-requirements are not generally known. It is the general feeling among the operators that this subject is of sufficient importance to warrant special treatment on the part of the manufacturers.

Motor-truck ratings have been discussed pro and con over a period of years with nothing tangible developed that the operator could use as a guide in the purchase of motor vehicles for a definite transportation job. I have attempted to correlate sufficient data furnished by the manufacturers and, using their own advertised ratings, to show first the lack of consistency and second the lack of standardization.

The method used in developing this practical rating is simply taking the manufacturer's advertised gross vehicle weight with his advertised standard axle ratio, equipping that vehicle with sufficient tire size to comply with the Rubber Association's rating for the particular gross vehicle weight and for the performance factor, and computing the grade ability at 20 m.p.h.

As a check on the strength of the component units in the vehicle, the front-axle-knuckle diameter at the inside bearing, the rear axle, outside tube diameter full-floating type, section modulus of frame, clutch area, effective braking area, and engine displacement, all computed in terms of 1000 lb. of gross vehicle weight, maximums, minimums and averages have been set up for all classes of vehicles.

To the operator, it is intended as a guide to rate a vehicle for a specific job. To the manufacturer, we trust it will be used for the production of a better-balanced vehicle.

major differences in these batteries are quality of the material, type of insulation, plate area and price.

Those of us on the operating side are interested in this battery problem: First, in having a battery furnished with our vehicles that can be readily serviced in the field; second, to have a battery of sufficient size for a given engine size that will assure us of satisfactory starting at 0 deg. fahr.; and third, sufficient lighting ability to carry, in addition to normal lighting, special lights required to meet with various State requirements.

It has been my observation that if a battery is large enough to give the required starting ability, little if anything is gained by increasing battery size for increased lighting load, as the difficulty, if any, is most generally with the generator size; therefore, in the data I will present, we will analyze the battery primarily from the standpoint of starting characteristics.

In discussing this problem with some of the manufacturers, it appears as though they view the situation from the standpoint of the characteristics of a new battery fully charged; whereas, in actual operation, the average age of the batteries in a fleet will vary from 9 to 12 months and they are rarely if ever fully charged, especially during winter operation. It would therefore appear more logical from the operators' viewpoint of what can be expected from the battery at 0 deg. fahr. for a period of 5 min. to 3 volts. This is about the minimum factor of safety that a fleet operator should have.

It is recognized that, with varying engine designs, we will have a varying starting requirement; however, for comparative purposes, I have shown graphically the wide variation in battery size furnished for a given engine displacement. It is not reasonable to expect that there actually would be as much difference in engine-starting requirements as is indicated by the variation in battery sizes. This is more or less confirmed by the vehicle manufacturers' inability to furnish information on minimum cranking speed of an engine for starting and at what minimum temperature the battery used will start the engine. Assuming that the engineer on the job has de-

termined the proper-sized battery to use, then it is apparent that the purchasing department has had the final vote on the size of battery that is actually furnished. I conclude from the foregoing that the manufacturers should adhere more closely to the average battery size for a given engine displacement to minimize winter starting-difficulties.

Starting Motors

Many cases of starting difficulty are not on account of improper battery size. See Table 1. Too frequently we find, in large engines, due to limited space, that undersized starting motors are installed on account of insufficient room to install the proper size. It is obvious that such an installation will be troublesome, with no correction in the field possible. I have attempted to develop a simplified form or starter rating for a given engine-size but, due to the many variables that enter, I fear the rating has been lost beyond redemption. It is quite obvious that the manufacturers do not know the effort required to crank the engine at starting speed at 0 deg. fahr., or we would not find so many variations in starting motors. From field results obtained, it is apparent that the trial-and-error method is generally used.

Generators

I am inclined to feel that many of our difficulties in the field which are laid to improper battery size or an inadequate starting motor can be traced to the generator. See Table 2. The majority of our generators today are of the third-brush regulated-type, with a maximum output, hot, of approximately 14 amp. For example, consider Engine *A*, with a generator output of 14 amp. tied into a battery having a No. 1 S.A.E. classification. Likewise Engine *D* with a maximum output of 12 amp. charging a battery of No. 9 S.A.E. classification. The first battery at the 20-hr. rate has a capacity of 80 amp-hr., whereas the second battery, at the same rate, has a capacity of 140 amp-hr. It is obvious to me, considering two motor vehicles doing the same amount of running, one having Engine *A* and the other Engine *D* with the corresponding generator and battery set-up and assuming that the running was sufficient so that No. 1 battery is just kept fully charged, that the No. 9 battery would never be more than two-thirds fully charged.

Referring for the moment to the starting characteristics on Engine *D*, it will be noted from Table 1 that the main and rod bearing area is twice that of Engine *A* and the starting torque required is 20 per cent more at 0 deg. fahr. The vehicle carrying Engine *D* then will discharge its battery, assuming the same number of starts as with Engine *A*, not on account of insufficient battery size but due to the inability of the generator to replace the energy used. The generator on Engine *C*, whose output dropped from 18 amp. cold to 12 amp. hot at a loss of one-third of its output, surely indicates improper design.

Many cases of generator failure have come to my attention where the fault lies in the application of the generator to the engine rather than in the generator itself. Considerable improvement can be made in deflecting manifold heat from the generator and providing better cooling for it. Other cases of generator failures to keep batteries charged when of a third-brush type have been corrected by installing voltage regulation.

Ignition

We have made an analysis of practices in the industry as regards coil, condenser and distributor specifications, but did not develop sufficient data to present at this time; however, from information at hand which was made available to us, it appears as though it will require considerable time to unravel

Table 2—Standard Equipment; Truck Generator-Characteristics

Engine No.	Maximum Current Amp. Hot	Maximum Current Amp. Cold	S. A. E. Battery No. Standard Equipment	S. A. E. Battery Rating 20-Hr. Rate	S. A. E. Battery Rating 300-Amp. Rate	Generator Rating, Watts Cold	Generator Rating, Watts Hot
A	14	17	1[a]	85	1.7	128	87
B	14	17	1[a]	85	1.7	174	105
C	12	18	7[a]	108	3.0	162	105
D	12	16	9[a]	144	5.5	154	113
E	13.5	15	....	96	....	...	...
F	17	20	1 H	102	3.1	174	138
G	15.5	22.5	4 H	153	6.6	207	115
H	10	22	4 H	150	6.0	103	79
I	10	22	3 H	135	5.0	103	79
J	10	22	4 H	150	6.0	103	79
K	10	22	3 H	135	5.0	103	79
L	..	..	14[a]	123	2.75	...	...
M	14.5	19.5	....	87	....	...	...

[a] Old S. A. E. Ratings

Table 1—Starting Characteristics

Engine No.	Displacement Cu. In.	Main and Rod Bearing Area Sq. In.	Compression Ratio	Starting Motor Torque, Lb-Ft.	Minimum Cranking Speed to Start, R. P. M.	Ratio: Armature to Flywheel	Torque at Flywheel Lb-Ft.	Starting Torque Required Lb-Ft. 0 Deg. Fahr.	Starting Torque Required Lb-Ft. 32 Deg. Fahr.	S. A. E. Oil Required at 0 Deg. Fahr.	S. A. E. Battery No.	S. A. E. Minimum at 300-Amp. Rating	No. of Minutes the Battery Will Crank the Engine at: Deg. Fahr.	Minimum Temperature at Which the Battery Will Start the Engine, Deg. Fahr.
A	201.3	73.07	5.80	12	30	16.22	194	0.6 Hp.	...	20-W	1[a]	1.7	1.75 at −10	−40
B	217.8	79.47	5.60	12	30	16.22	194	0.675Hp.	...	20-W	1[a]	1.7	2.4 at −10	−40
C	241.5	94.16	5.40	15	30	16.22	243	0.69 Hp.	...	20-W	7[a]	3.0	3.9 at −10	−40
D	309.6	148.62	4.70	28	30	11.27	315	1.0 Hp.	..	20-W	9[a]	5.5	6.2 at 0	−40
E	221.0	84.00	5.32	..	..	11.20	...	.....	...	20	..	...	1.5 at −30	−30
F	230.0	123.50	4.60	15	..	10.50	157	.....	...	20	1 H	3.1	.....	....
G	358.0	164.80	5.10	22	..	11.54	254	.....	...	40	4 H	6.6	.....	....
H	453.0	178.00	5.10	22	20	11.50	254	.....	150	30	4 H	6.0	5 at 25	+25
I	358.0	149.00	5.20	22	20	11.50	254	.....	125	30	3 H	5.0	4 to 6 at 25	+25
J	407.0	178.00	5.10	22	20	11.50	254	.....	150	30	4 H	6.0	5 at 25	+25
K	315.0	149.00	5.25	22	20	11.50	254	.....	125	30	3 H	5.0	5 at 25	+25
L	228.0	138.00	5.16	..	125	10.18	...	.....	...	30	14[a]	2.75	.....	....
M	206.8	90.00	5.45	..	30	14.66	...	95	...	10	...	....	1.5 at −20	−20

[a] Old S. A. E. Ratings

Table 3—Trucks; Advertised Gross Vehicle Weight

Make and Model	Chassis Price[a] per 1000 Lb. of Chassis Weight	Ratio of Specifications[a] to Advertised G.V.W./1000: Chassis Price	Piston Displacement Cu. In.	Clutch Area Sq. In.	Brake Area Sq. In.	Frame Section Modulus	Front Axle Knuckle Diameter, In.	Diameter Full-Floating Rear Axle Tube, In.	Grade, Per Cent at 20 M.P.H.
8,000 to 10,000 Lb.									
1	$180	$55	23.70	11.10	20.50	0.572	0.169	0.383	3.73
2	140	47	22.20	10.30	22.00	0.523	0.141	0.363	4.10
3	138	51	26.00	12.00	40.50	0.635	0.118	0.433	5.00
4	165	55	22.95	10.30	22.00	0.516	0.108	0.403	4.26
5	175	60	21.58	8.54	25.38	0.597	0.174	0.263	3.32
6	176	63	25.50	12.15	25.80	0.517	0.181	0.278	4.95
7	236	119	30.00	15.45	35.00	0.680	0.219	0.313	5.70
Maximum..	236	119	30.00	15.45	40.50	0.680	0.219	0.433	5.70
Minimum...	138	47	21.58	8.54	20.50	0.516	0.108	0.263	3.32
Average....	173	64	24.56	11.41	27.31	0.577	0.159	0.348	4.44
10,000 to 12,000 Lb.									
8	$240	$84	18.70	11.60	21.60	0.480	0.136	0.232	3.48
9	179	49	20.70	8.98	16.25	0.548	0.137	0.333	3.53
10	163	55	22.80	9.43	25.40	0.515	0.163	0.510	3.20
11	191	67	22.80	10.05	22.34	0.725	0.163	0.350	3.93
12	200	69	20.75	9.13	20.30	0.660	0.148	0.318	4.28
13	192	58	21.04	8.76	19.50	0.533	0.095	0.357	3.85
14	198	68	21.20	10.60	26.30	0.487	0.155	0.214	3.03
37	164	51	21.95	9.00	23.40	0.470	0.143	0.214	4.18
Maximum..	240	84	22.80	11.60	26.30	0.725	0.163	0.510	4.28
Minimum...	163	49	18.70	8.76	16.25	0.470	0.095	0.214	3.03
Average....	191	63	21.24	9.92	21.88	0.552	0.142	0.316	3.68
12,000 to 14,000 Lb.									
15	$207	$74	20.22	10.22	26.90	0.533	0.125	0.269	2.78
16	218	64	19.30	10.50	18.50	0.698	0.130	0.280	3.76
17	246	80	21.90	9.43	27.05	0.605	0.146	0.313	3.97
18	201	67	17.70	7.37	20.20	0.448	0.080	0.302	3.00
19	230	75	17.13	8.58	23.30	0.565	0.125	0.193	3.03
20	235	80	18.48	9.50	21.55	0.418	0.135	0.193	2.78
21	206	71	19.18	11.38	23.70	0.452	0.146	0.208	3.73
38	197	63	22.30	10.93	24.10	0.490	0.125	0.231	3.93
Maximum..	246	80	22.30	11.38	27.05	0.698	0.146	0.313	3.97
Minimum...	197	63	17.13	7.37	18.50	0.418	0.080	0.193	2.78
Average....	217	72	19.53	9.74	23.16	0.531	0.127	0.246	3.37
14,000 to 16,000 Lb.									
22	$270	$86	17.70	9.58	26.10	0.394	0.125	0.179	2.86
23	265	85	20.15	8.07	28.20	0.517	0.116	0.250	4.12
24	302	96	18.40	10.00	24.60	0.557	0.087	0.250	3.02
25	410	189	17.18	9.35	28.95	0.520	0.083	.....	2.48
26	...	96	16.00	8.23	23.60	0.440	0.117	0.200	2.35
27	410	179	22.90	15.78	29.80	0.510	0.120	0.172	4.15
39	250	75	17.85	16.50	19.25	0.439	0.133	0.192	2.57
Maximum..	410	189	22.90	16.50	29.80	0.557	0.133	0.250	4.15
Minimum...	250	75	16.00	8.07	19.25	0.394	0.083	0.172	2.35
Average....	318	115	18.60	11.07	25.79	0.454	0.112	0.207	3.08
16,000 to 18,000 Lb.									
28	$295	$111	19.70	9.42	20.30	0.743	0.125	0.219	3.00
29	349	108	16.10	8.76	27.08	0.487	0.076	.....	2.88
30	278	90	17.00	8.97	22.96	0.563	0.107	0.168	2.67
31	276	95	21.20	10.48	24.65	0.432	0.103	0.158	4.25
32	318	120	17.80	10.18	25.20	0.412	0.125	0.177	3.98
Maximum..	349	120	21.20	10.48	27.08	0.743	0.125	0.219	4.25
Minimum...	276	90	16.10	8.76	20.30	0.412	0.076	0.158	2.67
Average....	303	105	18.36	9.56	24.04	0.527	0.107	0.181	3.39

[a] Chassis Price Based on *Commercial Car Journal*, October, 1934, Less National Fleet Discount

(Continued on next page)

the inconsistencies contained therein. In general we can state that, in the light and the medium-duty field where high-compression high-speed engines are prevalent and the ignition job is the most difficult, the ignition equipment is the poorest; and that, in the heavier-duty type where compression ratios and engine speeds are lower and likewise the ignition job more reasonable, we find the equipment highly satisfactory. It is therefore apparent that there is no lack of knowledge, but rather a lack of appreciation.

From the standpoint of maintenance of the engine, the ignition equipment is causing the most trouble; due, first, to inadequate ignition equipment and, second, to improperly trained mechanics who have insufficient test equipment. By inadequate ignition equipment I mean simply that coil condensers and distributors furnished as standard equipment are not satisfactory for the job, that is, coils either of insufficient capacity or poorly constructed, which cut out at high speed; condensers of low capacity and poor quality that break down rapidly; distributor caps that develop heat cracks and short-circuit out; and breaker points that are too light and rapidly burn away.

In view of the fact that engine failures are the most common cause of delays which are expensive and conducive to higher operating costs, and that the majority of these failures are traceable to defective or inadequate ignition equipment, would it not appear logical to give this equipment the same consideration and the same careful treatment that is given to other units of the vehicle? I feel that I can safely express the opinion of the operating fraternity in that we would favor reducing the bright parts and plating expense by an amount equal to that necessary to install high-grade ignition-equipment even on our lighter-duty equipment.

Truck Rating

The subject of motor-truck ratings has been under consideration for quite some time and but little if any headway has been made, due primarily to the fact that the approach has been from a theoretical standpoint. Further, it seems that, in the discussions of the rating problem, there appears to be an element of fear on the part of the manufacturers' engineers to present a united front on the rating matter. It must appear to the regiment of intelligent operators, who have either sat in on these discussions or read the results of them, that little if any serious effort is really being made to develop a rating. Probably we are somewhat confused on what the operating personnel would like in the way of a motor-truck rating or a measuring stick to enable it to size-up a certain motor vehicle to determine, first, if it is a worth-while transportation-unit and, second, if it is a unit that is fitted to the particular job the personnel has in mind. With so simple a premise, it does not appear to me that the subject warrants being dragged out and lost in the highly theoretical discussions that have ensued.

To crystallize, somewhat, our thinking in terms of a motor-truck rating, and to simplify the matter to a point at which the average operator can make use of it, I propose to set up a number of recommended standards for comparative purposes which, to me, constitute the only practical way in which to rate a motor vehicle. Let us assume, for clarity, that we classify motor trucks roughly, as follows:

Rating, Tons	Gross Vehicle Weight, Lb.
1½	8,000 to 10,000
2	10,000 to 12,000
2½	12,000 to 14,000
3	14,000 to 16,000
3½	16,000 to 18,000
4	18,000 to 20,000
5	24,000
7	30,000

A motor truck, to qualify in any particular classification, must have certain definite qualities as regards strength, performance and maneuverability. See Table 3. We can assume, without question, that the subject of strength of materials is fairly well standardized; sufficiently so, at least, for comparative purposes. Our problem then becomes one of where these materials are used, and how; or, should I say, how much. The question of maneuverability is one, primarily, of vehicle size and design. The last element and by far the most important, the performance factor, is the most perplexing. In vehicle performance, the operator is not wholly concerned with the ability of the job to do certain stunts, so to speak, but with the ability of that vehicle under day-in-and-day-out operation to handle, satisfactorily and economically, a given rated load at governed speed. We have on record many cases of failures of models of trucks from reputable manufacturers which appear on paper to have all the prerequisites of good-performing jobs but which, due to in-

Table 3—Trucks; Advertised Gross Vehicle Weight (*Continued*)

Make and Model	Chassis Price per 1000 Lb of Chassis Weight	Ratio of Specifications[a] to Advertised G.V.W./1000: Chassis Price	Piston Displacement Cu. In.	Clutch Area Sq. In.	Brake Area Sq. In.	Frame Section Modulus	Front Axle Knuckle Diameter In.	Diameter Full-Floating Rear Axle Tube, In.	Grade, Per Cent at 20 M.P.H.
18,000 to 20,000 Lb.									
33	$336	$95	16.30	9.35	18.32	0.450	0.1114	.....	2.32
34	342	118	20.05	9.62	20.45	0.625	0.1052	0.192	3.78
35	364	108	17.40	10.62	23.60	0.742	0.0640	.....	2.98
36	415	154	15.50	8.86	21.30	0.473	0.1090	0.173	5.12
Maximum..	415	154	20.05	10.62	23.60	0.742	0.1114	0.192	5.12
Minimum...	336	95	15.50	8.86	18.32	0.450	0.0640	0.173	2.32
Average....	364	119	17.31	9.61	20.92	0.573	0.0974	0.183	3.55

[a] Chassis Price Based on *Commercial Car Journal*, October, 1934, Less National Fleet Discount

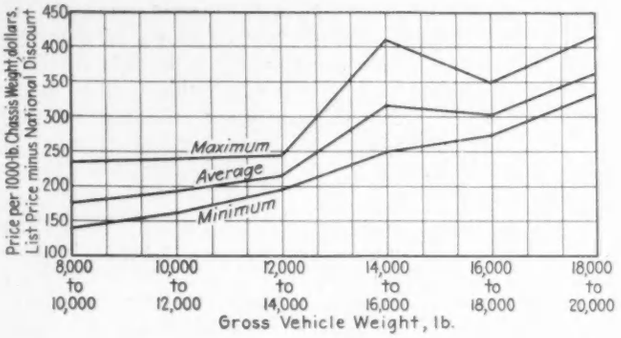


Fig. 2—Curves Showing Price per 1000 Lb. of Chassis Weight

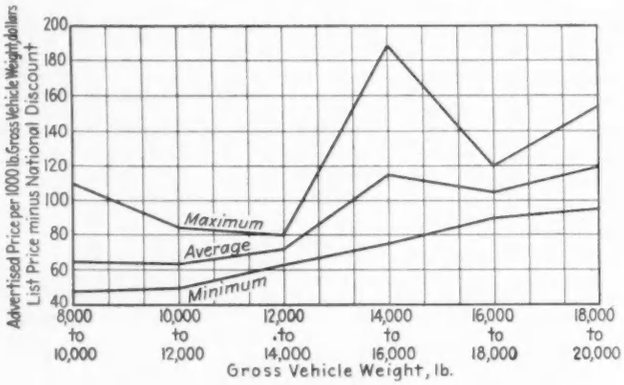


Fig. 3—Curves Showing Advertised Price per 1000 Lb. of Gross Vehicle Weight

coherence in design, develop trouble in certain units which transforms them into very bad-performing jobs.

Operators, as a class, are not desirous of building or designing motor vehicles; but they are desirous of fitting certain motor-vehicle offerings into their various fleet jobs in such a way that each unit installed will perform in the most efficient manner. Due to the lack of proper standards for comparison, the operator is forced to do a great deal of experimental work in the field and, about the time he has arrived at some conclusions, so many changes have been made in the various models that are offered that his previous data are of little value in the repurchase of equipment. I am of the opinion that many motor-vehicle manufacturers have either lost sight of or are reluctant to admit that operators today are purchasing transportation and not merely motor vehicles. I likewise have the feeling that too many sales departments are imbued with the idea of order-taking rather than with the sale of transportation units. I propose to take the offerings on the present market, allocate them according to the previous classification and set up a measure for a comparison of the major component units. I have elected to assume that if a front axle, for example, is consistently designed, that an indication of its strength can be determined from the outside diameter of the steering knuckle at the inside bearing. By the same reasoning, the load-carrying ability of the rear axle is determined, more or less, by its bearing capacity and, for a quick check on the full-floating type, the outside tube diameter is adequate. Likewise, the section modulus of the frame should determine its strength, all other factors being equal. If, in addition, we know the displacement of the engine, area of the clutch and effective area of the service brakes, we have a vehicle well ear-marked.

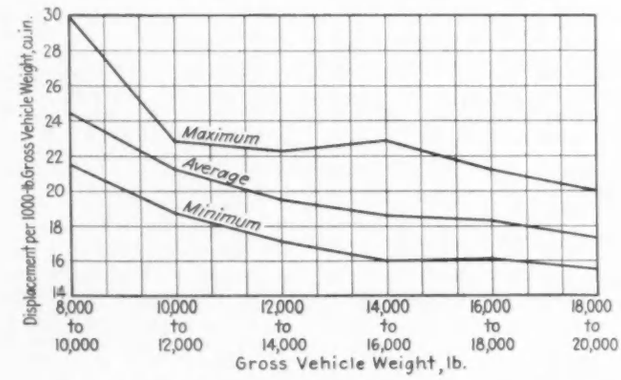


Fig. 4—Curves Showing Piston Displacement per 1000 Lb. of Gross Vehicle Weight

With the constantly increasing demand for improved highway performance, I am assuming, for purposes of comparison, a grade ability of 3½ per cent at 20 m.p.h. in high-gear operation. The equipment has been classified according to manufacturers' advertised gross vehicle weight. I have used the advertised standard axle ratio and have determined the performance factor of these vehicles, using a tire size as recommended by the Rubber Association to carry the advertised gross weight.

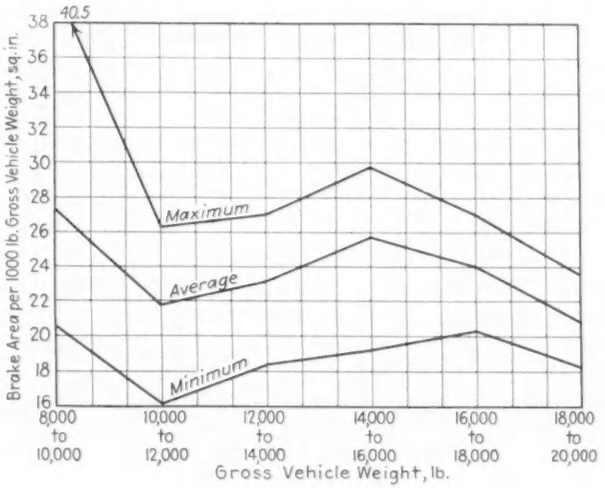


Fig. 5—Curves Showing Brake Area per 1000 Lb. of Gross Vehicle Weight

Some of these data are rather illuminating. The curves presented in Figs. 2 to 10 show maximum, minimum and average of the vehicles in the various classifications. It will be noted particularly that the poorest performer in the first group has a grade ability in excess of 3¼ per cent at 20 m.p.h. with an average of better than 4¼ per cent. As the gross vehicle weight increases, the performance factor decreases.

For the 10,000 to 12,000-lb. group, the gross vehicle weight averages 3.68 per cent; 12,000 to 14,000 lb., 3.37 per cent; 14,000 to 16,000 lb., 3.08 per cent; and 16,000 to 18,000 lb., 3.39 per cent. These averages are not bad and fall roughly into our goal of 3½ per cent; however, the minimums tell an entirely different story; that is, 10,000 to 12,000 lb., 3.03 per cent; 12,000 to 14,000 lb., 2.78 per cent; 14,000 to 16,000 lb., 2.35 per cent; 16,000 to 18,000 lb., 2.67 per cent; and 18,000 to

20,000 lb., 2.32 per cent. It is our belief that there are many jobs being manufactured and sold today that do not come up to the expectancy of either the operators or the various state-highway departments. It is likewise quite obvious that the heavy-duty manufacturers are giving considerable attention to this factor as indicated by the high average shown as compared to some of the offerings in the medium-duty field.

Space does not permit the analyzing in detail of the variations between makes and models of the various factors under

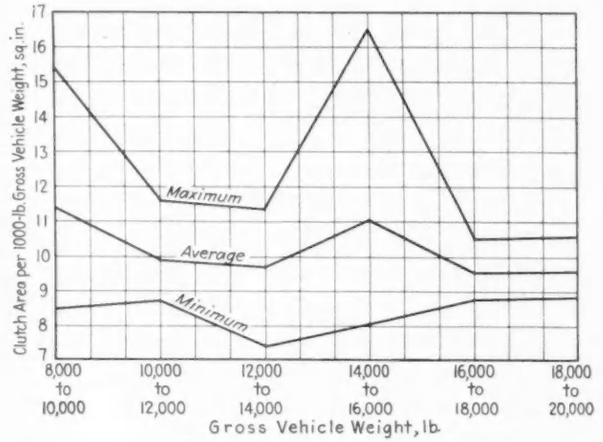


Fig. 6—Curves Showing Clutch Area per 1000 Lb. of Gross Vehicle Weight

consideration; however, the data presented are self-explanatory.

I wish to direct attention to the chassis price per 1000 lb. of chassis weight; likewise to the price per 1000 lb. of advertised gross vehicle weight. These prices are based on quotations shown in the *Commercial Car Journal*, Oct. 1, 1934,

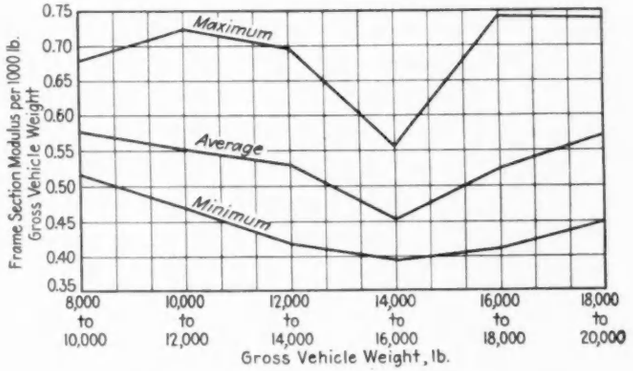


Fig. 7—Curves Showing Frame-Section Modulus per 1000 Lb. of Gross Vehicle Weight

less the National Fleet discount. Comparing vehicle No. 5 with vehicle No. 6 shows the unit price on a chassis-weight basis to be approximately the same, yet No. 5 costs less per 1000 lb. of advertised gross vehicle weight. It is obvious that either the No. 6 truck is over-rated or that the No. 5 truck is under-rated. Referring further to the 8000 to 10,000-lb. gross-vehicle-weight class, truck No. 5 offers 8.54 sq. in. of clutch area as compared to the average in this class of 11.41 sq. in. Obviously, this job does not have sufficient clutch area.

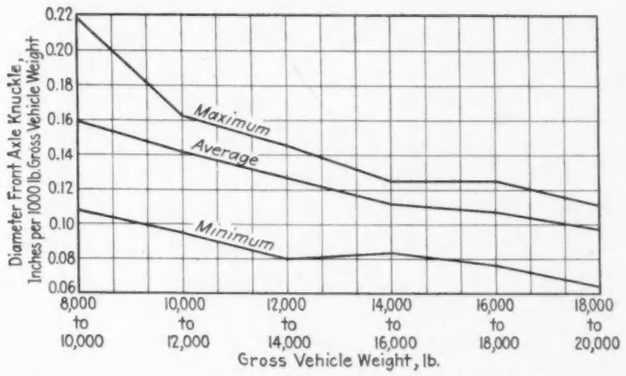


Fig. 8—Curves Showing the Diameter of the Front-Axle Knuckle in Decimals of an Inch per 1000 Lb. of Gross Vehicle Weight

A detailed comparison of the various data will show a multitude of inconsistencies. One of the committee suggested to me that we incorporate in a truck rating a factor taking into consideration the stop-start service such as confronts milk route and department-store deliveries. For this

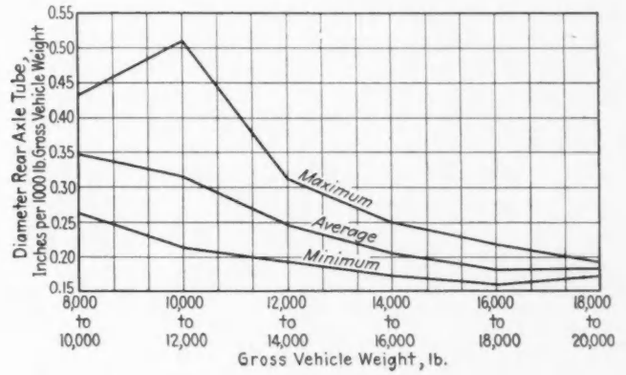


Fig. 9—Curves Showing the Diameter of the Rear-Axle Tube in Decimals of an Inch per 1000 Lb. of Gross Vehicle Weight

type of work, the clutch size and effective braking area play an important part and I feel that, with these data before that particular operator, he would not select the No. 5 vehicle. Operators requiring strength in certain other component units could easily make their selection by similar reasoning.

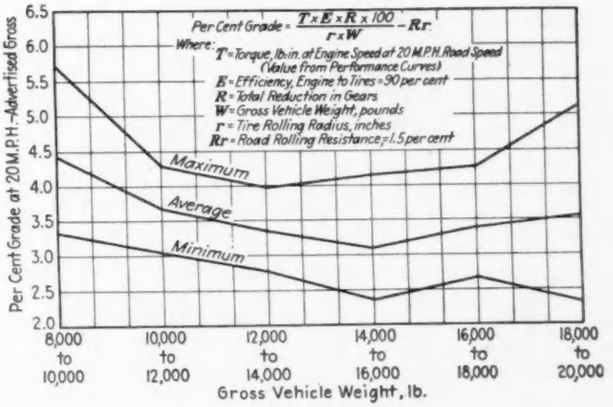

Per Cent Grade = (T × E × R × 100) / (r × W) − Rr
Where: T = Torque, lb-in. at Engine Speed at 20 M.P.H. Road Speed (Value from Performance Curves)
E = Efficiency, Engine to Tires = 90 per cent
R = Total Reduction in Gears
W = Gross Vehicle Weight, pounds
r = Tire Rolling Radius, inches
Rr = Road Rolling Resistance = 1.5 per cent
Per Cent Grade at 20 M.P.H.-Advertised Gross
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
Maximum
Average
Minimum
8,000 to 10,000
10,000 to 12,000
12,000 to 14,000
14,000 to 16,000
16,000 to 18,000
18,000 to 20,000
Gross Vehicle Weight, lb.

Fig. 10—Curves Showing Grade Ability at 20 M.P.H.

Table 4—Trucks Used as Tractor Units

Make	Chassis Weight, Lb.	Wheel-base, In.	C-A Dimen-sion, In.	Frame Width, In.	Rear-Spring Deflection, In.
Rated at 8,000 to 10,000-Lb. G.V.W.					
1	2,600	148	63.00	33.9	2.50
2	3,100	131	51.50	36.0	2.00
3	3,172	131	51.19	38.0	4.00
4	3,105	131	51.50	36.0	3.75
5	2,945	133	52.38	32.1	3.25
6	3,185	130	48.13	33.9	4.76
7	4,020	132	60.00	34.0	2.75
Maximum...	4,020	148	63.00	38.0	4.76
Minimum...	2,600	130	48.13	32.1	2.00
Rated at 10,000 to 12,000-Lb. G.V.W.					
8	4,035	149	65.00	34.00	4.25
9	2,885	148	63.06	34.00	2.60
10	3,410	135	51.50	34.00	3.63
11	3,500	137	51.13	34.00	6.00
12	3,800	137	51.13	34.00	6.00
13	3,270	140	60.00	36.00	4.00
14	3,605	136	52.38	32.06	3.25
37	3,260	140	60.00	34.00	3.00
Maximum...	4,035	149	65.00	36.00	6.00
Minimum...	2,885	135	51.13	32.06	2.60
Rated at 12,000 to 14,000-Lb. G.V.W.					
15	4,600	155	72.00	34	3.437
16	3,675	157	72.03	34	2.500
17	3,900	137	51.13	34	7.500
18	4,130	142	60.00	34	4.250
19	4,225	145	61.38	34	3.750
20	4,405	144	72.00	34	4.000
21	4,130	141	60.00	34	3.063
38	3,865	142	60.00	34	2.937
Maximum...	4,600	157	72.03	34	7.500
Minimum...	3,675	137	51.13	34	2.500
Rated at 14,000 to 16,000-Lb. G.V.W.					
22	4,480	149	65.00	34	4.000
23	4,500	137	51.13	34	6.500
24	4,470	142	60.00	34	4.125
25	6,925	94	72.00	34	3.750
26	.....	156	84.00	34	3.938
27	6,844	150	60.40	34.12	4.688
39	4,475	142	60.00	34	3.000
Maximum...	6,925	156	84.00	34.12	6.500
Minimum...	4,470	94	51.13	34	3.000
Rated at 16,000 to 18,000-Lb. G.V.W.					
28	6,050	175	82	34	5.450
29	4,955	142	60	34	2.875
30	5,300	145	59.75	34.12	3.812
31	5,870	141	60	34.06	3.125
32	6,400	154	84.25	34	3.875
Maximum...	6,400	175	84.25	34.12	5.450
Minimum...	4,955	141	59.75	34	2.875
Rated at 18,000 to 20,000-Lb. G.V.W.					
33	5,344	165	84.75	33.94	1.500
34	6,550	175	82.00	34.00	4.460
35	5,635	145	60.00	34.06	3.000
36	7,225	159	95.00	34.00	3.250
Maximum...	7,225	175	95.00	34.06	4.460
Minimum...	5,344	145	60.00	33.94	1.500

The matter, then, of rating a motor truck for a certain type of work becomes relatively simple for even the average operator, for it is obvious that the operator is not willing to pay a high price per pound of chassis weight for a vehicle having major units bordering on the minimum side of the industry. It is logical to assume that he will attempt to obtain as many of these units, bordering on the maximum afforded by the industry, at as near the minimum price as possible. I would then define a 1½-ton truck as one having a gross vehicle weight of from 8000 to 10,000 lb.; stripped-chassis weight, approximately 3200 lb.; piston displacement, not less than 22 cu. in. per 1000 lb. of gross vehicle weight (G.V.W.); clutch area, not less than 11 sq. in. per 1000-lb. G.V.W.; effective brake area of not less than 27 sq. in. per 1000-lb. G.V.W.; frame-section modulus 0.577 per 1000-lb. G.V.W.; front-axle-knuckle diameter, inside bearings, 0.159 per 1000-lb. G.V.W.; diameter of full-floating rear-axle 0.348 in. per 1000-lb. G.V.W.; and the vehicle equipped with adequate tire size to comply with the Rubber Association's ratings for the maximum gross vehicle weight with the standard axle ratio to give a grade ability of not less than 3.5 per cent.

It is recognized that many other factors enter into the motor vehicle that have a definite bearing on its overall performance; however, it is expected that these units would be in keeping with a balanced design.

A definition for each group of vehicles can be worked out on a similar basis from the data presented, which will reduce to very definite limits the sizes of the component parts for the particular vehicle class. Time did not permit of my investigating the field beyond the 20,000 lb. G.V.W. class, but I trust that the Committee will see fit to continue its work in this field.

I will not attempt to give an analysis of the difficulties encountered by the operators in the selection of truck chassis for tractor work. Table 4 shows various vehicles rated as trucks and gives the frame width, *C-A* dimensions and spring deflection under load. It appears to me that there is a definite need on the part of the manufacturer of supplying to the operator an optional rear-spring set-up that will enable him to use tractors of different makes on shuttle operations, all having the same spring deflections and coupling height. Likewise, there would be a uniform *C-A* dimension to enable the operator to use the same king-pin location on different makes of tractors, all of which are working with the same trailer-body widths. With the ever-increasing popularity of the truck used as a tractor, more consideration should be given to the spare-tire carrier to enable the frame rails to be shortened without the loss of or necessity for making an entirely new tire carrier.

Conclusion

In conclusion, permit me to reiterate that the truck operator is not interested in attempting to design motor vehicles. We are interested wholly in the design of the vehicle from a standpoint of accessibility, safety and economy of operation. We have taken this opportunity through the Transportation and Maintenance Group of the Society to bring to the manufacturers' attention various inconsistencies in design and construction which are responsible for untold losses in fleet operation. A few dollars saved in the investment account in purchasing a vehicle that has been cut to the bone is false economy, as the little saving made initially is absorbed by increasing maintenance expense, costly road delays and loss of business through disappointed customers.

Flame Temperatures Vary with Knock and Combustion-Chamber Position

By Gerald M. Rassweiler and Lloyd Withrow
Research Physicist and Research Chemist, General Motors Corp.

TEMPERATURE measurements have been made along three lines through the combustion chamber of a gasoline engine running under non-knocking and under knocking conditions. The results show that, after passage of the flame fronts through portions of the charge located either near the point of ignition or near the center of the combustion chamber, the temperature rises continually until shortly before maximum pressure is reached. When the charge is completely inflamed, there is a temperature gradient along the length of the combustion space, the temperature at the spark-plug end being as much as 600 deg. fahr. higher than at the opposite end. These effects are explained on the basis of adiabatic compression and expansion of the gases during the combustion process.

Comparison of knocking and non-knocking explosions shows that in the knocking case: (*a*) the maximum temperatures are higher, (*b*) the maximum temperatures are attained earlier in the cycle, (*c*) the rate of cooling during the expansion stroke is greater, and (*d*) the exhaust temperatures are lower.

TEMPERATURES of the inflamed gases in an engine running on its own power have been measured by the sodium-line-reversal method. Although this system for measuring temperatures of inflamed gases has been used in the study of stationary flames for a number of years, only recently has it been applied to the hot gases in a gasoline engine. Data obtained in this way were reported first by Hershey and Paton[1] and later by Watts and Lloyd-Evans[2].

The experiments to be presented differ from those of these earlier workers in two important respects as follows:

(1) Each of the sets of prior published measurements was made at only one position in the combustion chamber, whereas the data described herein consist of measurements made at three different positions in the combustion space; namely, near the ignition point, near the center of the combustion space and, finally, in the region where the last part of the charge burns and where knock occurs when present. Thus, in the present investigation, it was possible to study the change in temperature of the gases near the spark plug as the flames swept on across the combustion chamber and to compare temperatures in different parts of the combustion chamber after inflammation was complete.

(2) The previously published investigations dealt only with non-knocking conditions, whereas the present experiments were made under both knocking and non-knocking conditions to obtain comparative temperature-time curves.

The nature of the sodium-line-reversal method of temperature measurement and the evidence for its validity have been discussed so frequently[3] that it scarcely seems necessary to repeat the details here; however, the operations involved in making a temperature measurement will be described briefly in connection with the procedure.

Apparatus

The apparatus consisted of the following essential parts which will be described in the order named:

(1) An engine fitted with windows on opposite sides of the combustion chamber so that light could be passed through the flames

(2) A light source consisting of a continuous radiator and operating in a manner such that its temperature could be varied

[This paper was presented at the Annual Meeting of the Society, Detroit, Jan. 18, 1935.]

[1] See *Physical Review*, 1932, vol. 40, p. 1053; Hershey and Paton. See also Bulletin No. 262, University of Illinois Engineering Experiment Station, 1933; Hershey and Paton.

[2] See *Proceedings of the Physical Society* (London), 1934, vol. 46, p. 444; Watts and Lloyd-Evans. See also *Engineering*, 1934 vol. 137, pp. 362 and 743; Watts and Lloyd-Evans.

[3] See Bulletin No. 262, University of Illinois Engineering Experiment Station, 1933; Hershey and Paton. See also *Proceedings of the Royal Society* (London), 1929, vol. A-123, p. 401; Griffith and Awberry. See also *Zeitschrift für Technische Physik*, 1928, vol. 48, p. 805; Henning and Tingwaldt. See also *Journal of the American Chemical Society*, 1931, vol. 53, p. 869; Jones, Lewis, Friauf, and Perrott. See also *Annalen der Physik*, 1914, vol. 44, p. 744; Kohn. See also *Industrial and Engineering Chemistry*, 1928, vol. 20, p. 1004; Loomis and Perrott.

(3) An optical system for directing the light from the source through the engine and focusing it on the slit of the spectroscope

(4) A spectroscope

(5) A stroboscopic shutter for limiting the time and duration of the observations to a definite known period in the engine cycle

(6) An optical pyrometer for measuring the temperature of the light source

(7) A pressure indicator

(1) The single-cylinder L-head engine in which these measurements were made was specially designed and built in this laboratory for use in studying absorption spectra of the gaseous charge[4]. It has a 2⅞-in. bore, a 4¾-in. stroke, and a compression ratio, as used for these experiments, of 4.4:1. The carburetor was a simple venturi and jet, the mixture ratio being adjusted by varying the height of the float bowls. All tests were run at full throttle, the speed and load being controlled by the dynamometer. No heat was added to the intake mixture. Jacket temperatures were kept at 212 deg. fahr. by means of an evaporative cooling system. Provision was made to spray very small quantities of sodium-carbonate dust into the intake air in order to color the engine flames when required.

The schematic sketch, Fig. 1, is a plan view of the combustion chamber. This shows the locations of the four windows with respect to the piston, valves, and spark plug.

The two windows, W_1 and W_2, were 2 in. long and ½ in. high, while the two smaller windows, the center line of which passed under the spark plug at *I*, were only ¼ in. in diameter. In order to avoid the presence of stagnant gases in any part of the combustion space, the large windows were mounted flush with the combustion-chamber walls and the small windows, which were shaped like truncated cones, were mounted so that the small ends projected about 1/16 in. into the combustion space. All of the windows could be readily removed for cleaning.

(2) A General Electric projection lamp with a wide strap filament served as a source of light. The temperature of the filament was controlled by varying the current through the lamp.

(3) The optical system used is shown in Fig. 1. Lens L_1 was so placed that light from a point on the filament, *F*, passed through the engine as a pencil of parallel rays. Lens L_2 focused an image of the filament on the stroboscopic shutter *T*, making possible a very sharp cut-off. Lens L_3 refocused the image on the spectrograph slit *S*.

The portion of the combustion chamber which could be investigated with the optical system in the position shown in Fig. 1 was confined to the region traversed by the light beam. This beam was limited in width to ¼ in. by the two diaphragms D_1 and D_2, and in height to ½ in., the height of the combustion space when the piston was at top dead-center. In addition to temperature measurements along line *AA*, determinations were made along lines *BB* and *CC* by moving the optical system and spectroscope.

(4) Two spectroscopes were used during the course of this work, a Bausch and Lomb quartz spectrograph fitted with an eye piece, and a small Gaertner spectrometer with a glass optical train. The spectrum photographs included herein were taken with the former instrument.

(5) The stroboscopic shutter consisted of a disc with a narrow slot of adjustable width near its periphery. Special mention is made of the fact that this disc was mounted on the crankshaft because such an arrangement eliminated all uncertainty about the time that the slot crossed the optical path. During the intake stroke, light from the source was cut off by use of a second slotted disc which was rotated at camshaft speed in a plane parallel to the first disc by means of a chain drive. The time and duration of the shutter opening were adjusted with the engine at rest.

(6) A Leeds & Northrup optical pyrometer of the disappearing filament type was used to measure the brightness temperature of the tungsten filament.

(7) The pressure indicator was of the carbon-stack type developed by Martin and Caris[5].

Procedure

Determining a temperature by the sodium-line-reversal method is essentially a simple process. With the apparatus

[4] See *Industrial and Engineering Chemistry*, 1933, vol. 25, pp. 923 and 1359; Withrow and Rassweiler, and Rassweiler and Withrow, respectively.
[5] See *Electrical Journal*, 1930, vol. 27, p. 87; Martin and Caris.

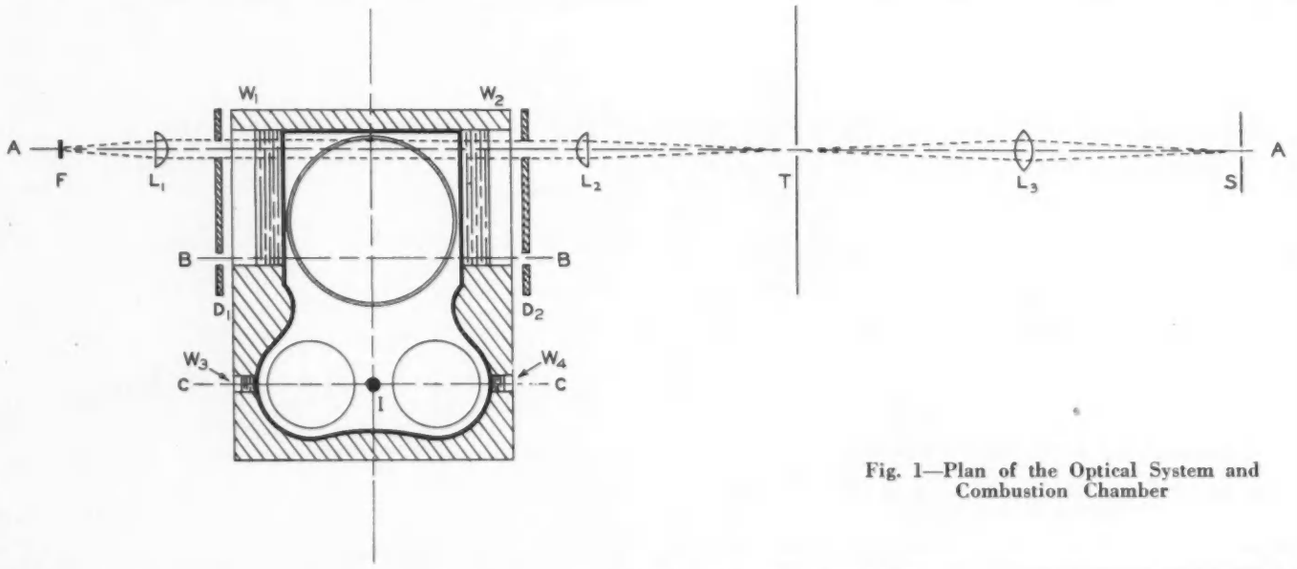


Fig. 1—Plan of the Optical System and Combustion Chamber

as shown in Fig. 1, the observer watches the change in the appearance of the spectrum as the temperature of the source is varied. The spectrum of the tungsten filament is continuous—that is, it contains all the colors, each one blending continuously into the next—and when the temperature of the filament is low, this continuous spectrum is very faint. A little sodium is now introduced into the engine. If the temperature of the filament is well below that of the engine flames, a bright-yellow sodium-emission line is seen superimposed upon the comparatively dim continuous spectrum from the source. This condition is illustrated by Spectrum 1 in Fig. 2, which was photographed with a filament-brightness temperature of 3620 deg. fahr. absolute. As the temperature of the source is raised, its continuous spectrum becomes brighter and the emission line gradually becomes less distinct. Spectra 1 and 2 in Fig. 2 show such a change. If the temperature of the source is still further raised until it is above the temperature of the flame, the bright sodium line completely disappears and is replaced by a dark absorption line. Such absorption lines are illustrated in Spectra 3 and 4 of Fig. 2. At the transition point where neither absorption nor emission can be seen at the position of the sodium line, the temperature of the source is equal to the temperature of the flame. The current through the filament is then read and the filament temperature obtained from a previously prepared plot of filament current against temperature. The details of the preparation of such a curve are given by Hershey and Paton[6]. In the case illustrated by Fig. 2, the temperature of the flame lay between 3815 and 4015 deg. fahr. absolute.

The measurements reported herein were all made visually. But it should be mentioned, perhaps, that the photographic method was also tried during the course of preliminary experiments. In fact, the spectra in Fig. 2 were exposed through the engine as a part of this preliminary investigation. The photographic method gave a permanent record that was easy to read and that was the result of integrating the effect of a large number of explosions. On the other hand, the visual method proved to be much more rapid and the results checked very closely those obtained photographically.

The visual determination of the reversal point in the engine is complicated by the flicker from the stroboscopic disc and by the variation in temperature from explosion to explosion. Near the reversal point the observer sees the line changing back and forth from emission to absorption because of the fact that some flames are hotter and some are cooler than the source. The observed variation of the temperature in successive explosions changes with the crankshaft angle and with the engine conditions. This fluctuation may amount to 200 deg. fahr. In the experiments to be described, the limits of this range were determined and the mean value taken. To decrease errors in judgment, independent determinations at each point were made by two observers.

The engine conditions maintained during these experiments were as follows:

Speed: 800 r.p.m.
Spark advance: 15 deg.
Mixture ratio: 80 per cent theoretical air (12 lb. of air per lb. of fuel).
Fuel: gasoline.
Jacket temperature: 212 deg. fahr.
Full throttle.

The non-knocking and knocking runs were made with

[6] See Bulletin No. 262, University of Illinois Engineering Experiment Station, 1933; Hershey and Paton.

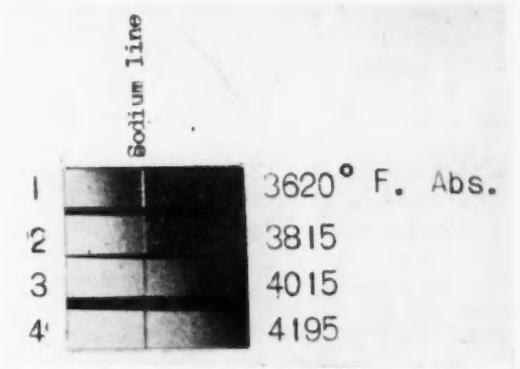


Fig. 2—Reversal of Sodium Line with Increase in Lamp-Filament Temperature

gasolines having octane numbers of 75 and 32, respectively. Mixture ratios were determined from exhaust-gas analyses.

Measurements have been made at three different positions in the combustion space with the optical paths normal to the general direction of flame travel, as indicated in Fig. 1. With the optical path at position *CC*, temperature measurements could be made as soon as the flames had spread about an inch away from the spark plug or about 10 deg. of crankshaft revolution after ignition had occurred. Subsequently, measurements could be made along line *CC* at any desired angle during the expansion stroke. Under the conditions of these experiments the flames reached position *BB* about 20 deg. of crankshaft revolution after ignition. With the optical path at position *AA*, measurements could not be made until the flames neared the end of their travel or, in terms of crankshaft revolution, not until about 45 deg. after ignition. It is important to note that at positions *BB* and *CC*, temperatures could be measured before the end of flame travel and therefore before maximum pressure was reached.

Data

In Figs. 3 to 7 inclusive, temperature measurements in degrees Fahrenheit absolute are plotted against the angle of crankshaft revolution at which the measurements were made. The points on each curve include several sets of values obtained on different days. While no effort has been made to distinguish between these various sets, mention should be made of the observation that measurements on any one day fell on a smoother curve than points taken on different days. Thus, it appears that changes in engine operation from day to day produced a part of the random variation of the points belonging to each curve.

Two average pressure-time curves were prepared: one from about 25 records taken during the course of the work under non-knocking conditions; the other from about the same number of records taken under knocking conditions. These curves are presented in some of the charts for comparison with the temperature curves. The abrupt rise in pressure which is characteristic of single knocking explosions has been incorporated in the average record; see Fig. 4, for example. Because of the variation in the time of occurrence of knock from explosion to explosion, this abrupt rise is not so distinct on a true average curve. The data will be discussed in the following order:

(1) Temperatures along lines *AA*, *BB* and *CC*, as shown in Fig. 1, with the engine operating under non-knocking conditions

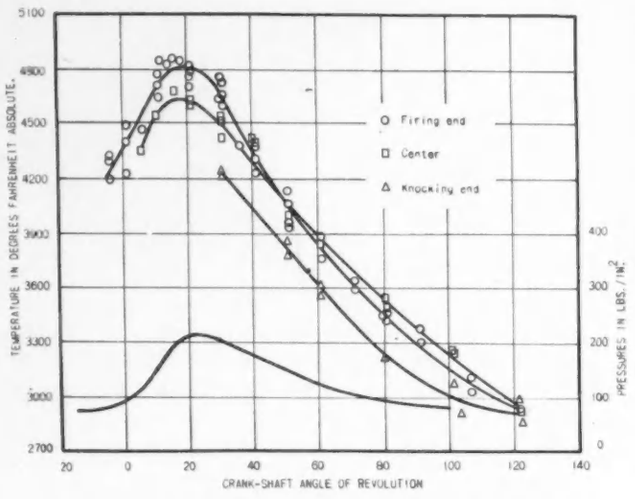


Fig. 3—Temperatures Measured at Three Different Positions in the Combustion Chamber under Non-Knocking Conditions

(2) Temperatures along the same three lines with the engine knocking

(3) The effect of knock on the temperatures at each of the three positions

(4) The temperature gradient along the lengths of the optical paths

Temperatures at Three Positions in the Combustion Chamber Under Non-knocking Conditions.—The upper curve in Fig. 3 shows the changes in temperature of the inflamed gas at the firing end (along line *CC* in Fig. 1) between 5 deg. of crankshaft revolution before top dead-center and 120 deg. past top dead-center. At 5 deg. before top dead-center, which was 10 deg. after ignition, the flame fronts had progressed about 1 in. away from the spark plug and the sodium-line-reversal temperature was about 4200 deg. fahr. absolute. Then, as the flames swept outward from the point of ignition and thereby increased the pressure, the temperature of the inflamed gases along *CC* rose steadily. By comparison of the general trend of this temperature curve with that of the pressure-time curve in Fig. 3, it is evident that the changes in temperature along the line *CC* are similar to the changes in pressure. Owing to the flat tops on these curves, it is rather difficult to make exact determinations of the angles at which temperature and pressure reached maximum values, but it appears that near the spark plug maximum temperature was reached a few degrees before maximum pressure. The data suggest the following explanation of the observed phenomena:

(1) As the pressure rose, the temperature increase near the spark plug was caused by adiabatic compression which raised the temperature despite heat losses to the walls.

(2) After the rate of pressure rise started to decrease but before this rate became equal to zero (at maximum pressure), the rate at which heat was being added to the gases at the firing end (by compression) just balanced the heat loss to the walls. At this time the temperature stopped rising and passed through a maximum.

The second curve in Fig. 3 was obtained with the optical path along line *BB* in Fig. 1 or near the middle of the combustion chamber. Measurements were begun about 5 deg. of crankshaft revolution after top dead-center when the slowest flames were reaching the optical path. At this angle, the observed temperature was about 4300 deg. fahr. absolute. Measurements at later angles indicated that the temperature increased with the pressure, this pressure rise being produced by chemical action in the flame fronts as they continued their courses across the combustion chamber. Again, maximum temperature was observed close to but slightly ahead of maximum pressure.

In many of the explosions the charge was not completely inflamed until about 30 deg. after top dead-center or 45 deg. after ignition. Therefore, temperature measurements along line *AA*—designated herein as the knocking end—were not started until about 8 deg. after maximum pressure, at which time the temperature was already decreasing. For this reason the value 4250 deg. fahr. absolute probably does not represent the maximum temperature at this position in the combustion chamber.

On comparing the three temperature curves in Fig. 3, the following observations are made:

(1) The temperatures, measured soon after the flames appeared in positions *AA, BB* and *CC,* do not differ widely from each other despite the differences in pressure at the time the charge inflamed in these three regions. However, it is important to note that the first point in each curve is not a true flame-front temperature because, owing to the shapes of the flames and the variation in the rate of flame travel from explosion to explosion, the earliest measurement that was practicable in each region was made partially through products of combustion and partially through flame fronts. If, at each position of the optical path, measurements could have been extended to earlier angles to obtain values more nearly characteristic of the flame fronts, the results would probably have been lower along lines *CC* and *BB* and higher along *AA* than is indicated by the first points of the corresponding curves in Fig. 3.

(2) Just after inflammation was complete throughout the combustion space, say at 35 deg. after top dead-center, there was an appreciable temperature gradient along the length of the chamber. The gases at the firing end were at a higher temperature despite the fact that, after their inflammation, they lost heat to the walls for some time before the gas at the other end of the chamber was inflamed. The explanation and significance of this temperature gradient will be taken up in a later section of this paper.

(3) The temperature gradient between the two ends of the combustion chamber persists throughout most of the expansion stroke. At 120 deg. after top dead-center, the two curves seem to be approaching each other. In fact, at this angle the observed difference in temperature between the two ends of the combustion chamber is not greater than the experimental error, which is larger at low than at high temperatures.

(4) The temperatures at the firing end and at the center approach each other quite rapidly as the piston moves downward. From the geometry of the combustion space, such an effect might be expected because, during the expansion stroke, the gas moving through position *BB* (Fig. 1) would come chiefly from the portion of the combustion chamber between *BB* and *CC*.

(5) The temperature curves at the firing end and at the center cross at 50 deg. after top dead-center. The difference in slopes of the two curves is not great and, consequently, this observation may not be very significant. If the difference is real, it may be caused by movement into the optical path *CC* of gases which have been cooled by contact with the chamber walls.

Temperatures at Three Positions in the Combustion Chamber Under Knocking Conditions.—With the engine knocking, temperatures of the inflamed gases were measured along lines *AA, BB* and *CC*. Except for the determinations made in the knocking zone, the same angles of revolution were covered at each position as in non-knocking combustion. These data are plotted against angle of revolution in Fig. 4.

The upper curve passes through points obtained at the firing end. At this position the temperature was about 4400 deg. fahr. absolute at 5 deg. before top dead-center. Measurements made at later angles while the pressure was still rising show that the temperature increased and reached a maximum value of 5000 deg. fahr. absolute. Then, as the pressure again decreased, the temperature fell off rapidly. The curve shows a sharp increase in temperature at 15 deg. past top dead-center. This course of the curve seems to be indicated by the data obtained and, in view of the general relationship between the courses of the temperature-time and the pressure-time curves, there is every reason to believe that, coincidental with knock, there is a sharp temperature increase near the spark plug caused by a sudden adiabatic compression of these gases. However, it is probably rather fortuitous that such a sudden rise should appear on a temperature curve averaged over a large number of explosions, because the variation in the time of knock from explosion to explosion would tend to obscure the effect. The agreement between the time of the sharp temperature increase and the time of sudden pressure rise in Fig. 4 is satisfactory in view of the fact that the curves do not represent single explosions.

The second curve in Fig. 4 shows that at the center of the combustion chamber the temperature rose with pressure until about 15 deg. past top dead-center. Between 10 and 20 deg. after top dead-center, the temperature readings were erratic, probably because of the fact that knock occurred in this interval. The average curve, as it is drawn, does not show a sudden temperature rise at the time of knock, although such a rapid temperature rise probably occurred during individual explosions. Temperature measurements at the knocking end could not, of course, be made until after knock occurred, at which time the temperature was already falling.

Comparing Figs. 3 and 4, it is evident that, as the temperatures decrease, the relative courses of the three curves are not the same in knocking as in non-knocking combustion. With the engine knocking, the temperatures at the firing end and center do not seem to equalize; but, instead, temperatures at the knocking end and center approach each other quite rapidly for about 20 deg. after knock occurred. To date, this behavior has not been explained in an entirely satisfactory manner. However, flame pictures indicate that at the instant knock occurs the sudden inflammation of the part of the charge which burns last sets up, in the inflamed gases, mass movements that are not present under non-knocking conditions.

Comparison of Knocking and Non-Knocking Temperature Curves.—Further comparisons of the temperature curves obtained under knocking and non-knocking conditions are made in Figs. 5, 6 and 7. Several differences are apparent:

(1) Under knocking conditions, the temperatures reach a maximum several degrees earlier than under non-knocking conditions. This difference is produced by rapid inflammation of the portion of charge which burns when the engine knocks.

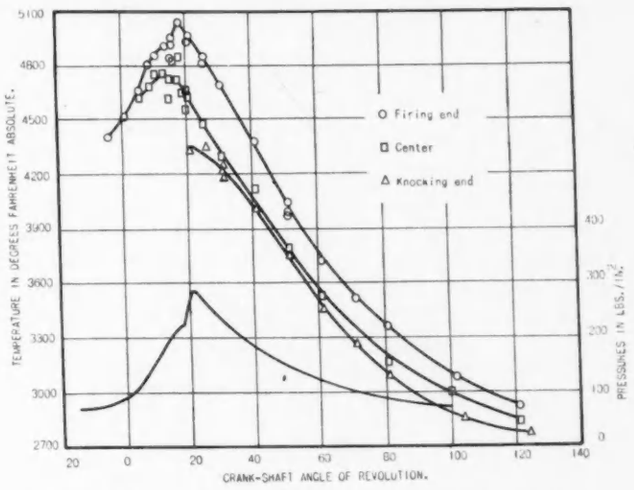


Fig. 4—Temperatures Measured at Three Different Positions in the Combustion Chamber under Knocking Conditions

(2) At all three positions the maximum temperatures measured under knocking conditions are higher than under non-knocking conditions. The difference in maximum temperature may be due, in part at least, to the fact that, in the knocking case, inflammation is complete at an earlier angle, at which time less energy has been absorbed by the piston and less energy lost to the walls.

(3) During most of the expansion stroke, the rate of cooling is greater under knocking than under non-knocking conditions. This observation is most significant. Consider, for example, the two curves in Fig. 5 which cross at 50 deg. past top dead-center. Obviously, the different rates of cooling at this angle cannot be attributed to different rates of expansion under the two conditions. Therefore there must have been greater heat loss to the walls in the knocking case. But at the point of intersection at 50 deg. after top dead-center, the greater heat loss to the walls in knocking combustion must be accounted for by differences between knocking and non-knocking explosions other than a temperature difference of the gases. In the course of the general investigation of the combustion phenomenon at this laboratory there have been observed two differences between knocking and non-knocking combustion which may partially account for the greater heat loss to the walls in knocking explosions. First, emission spectra have shown[7] that the continuous radiation at the red end of the spectrum is stronger under knocking than under non-knocking conditions; that is, there appears to be more black-body radiation in the former case. However, on the basis of quantitative measurements, Marvin, Caldwell and Steele[8] have recently concluded that there is very little black-body radiation from either knocking or non-knocking combustion. Second, flame pictures show appreciable mass movements of the gases as the pressure waves set up by knock pass back and forth through the combustion space[9]. The increased degree of turbulence resulting from this cause undoubtedly augments the rate of heat transfer to the walls. The effect on the engine of the higher rate of heat transfer to the jacket walls is a higher jacket temperature and a greater rate of pressure decrease which results in a loss of power as compared with non-knocking combustion. The fact that the two temperature curves cross at a somewhat later

[7] See *Industrial and Engineering Chemistry*, 1931, vol. 23, p. 769, and 1932, vol. 24, p. 528; Withrow and Rassweiler.
[8] See N.A.C.A. 1934 Report No. 486; Marvin, Caldwell and Steele.
[9] See *Industrial and Engineering Chemistry*, 1931, vol. 23, p. 769, and 1932, vol. 24, p. 528; Withrow and Rassweiler. See also *Automobile Engineer*, 1934, vol. 24, p. 385, Rassweiler and Withrow, and p. 281, Withrow and Rassweiler.

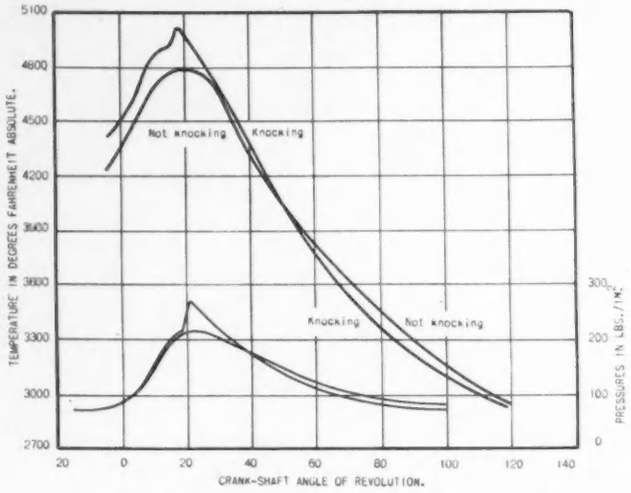


Fig. 5—Comparison of Temperatures at the Firing End under Knocking and Non-Knocking Conditions

angle in Fig. 5 than do the two pressure curves is not significant because of the limited portion of the combustion space covered by the temperature measurements shown in this one chart.

(4) The temperatures of the exhaust gases are lower when the engine is knocking than when it is not knocking. The greater heat loss through the cylinder walls during knocking combustion appears to be responsible for this difference in exhaust-gas temperatures.

The Temperature Gradient Along the Optical Path.—Inasmuch as there is a temperature gradient along the length of the combustion chamber, it might be expected that there would also be some temperature gradient along the lines *AA, BB* and *CC* across the combustion space. And, indeed, there is experimental evidence for the existence of such a temperature gradient, although no quantitative measurements have been made of the temperature differences along these lines. The evidence consists of the "self-reversal" of the sodium line. As the name implies, self-reversal of a spectrum line is caused by absorption within the radiating source itself. To produce this effect on the sodium line when measuring temperatures in the engine, two conditions must be fulfilled: (*a*) The concentration of atomic sodium must be sufficiently high to produce appreciable broadening of the line; and (*b*) the layers of gas close to the window nearest the spectroscope must be at a lower temperature than the gases in the central portions of the combustion space.

Self-reversal was sometimes observed in the engine when too large an amount of sodium carbonate was present in the flames. This condition is illustrated by the spectra in Fig. 8. In photographing these spectra, advantage was taken of the fact that, if a large puff of sodium-carbonate dust is introduced into the intake manifold with the engine running, the sodium concentration in the combustion chamber, as evidenced by the coloration of the flames, gradually decreases until the flames resume their normal colors. The upper four spectra were taken with the lamp turned off. After introducing a puff of sodium-carbonate dust, the first spectrum was photographed at once. The exposures of the next three spectra which in each case amounted to 15 sec. were begun at 30-sec. intervals. The sodium line in the upper spectrum shows the bright edges and dark center which characterize a self-reversed line. Owing to the decreased concentration of sodium, the fourth spectrum shows no self-reversal, although the engine conditions were the same as for the upper spectrum. The next four spectra were exposed in a similar way with the light turned on and show the same phenomena superimposed upon the continuous spectrum.

Inasmuch as the temperature is not uniform along the lines *AA, BB* and *CC,* there arises a question as to what temperature is being measured under such conditions by the sodium-line-reversal method. This question is partially answered by the work of Griffith and Awberry[10] who have shown that, if a measurement is made by the reversal method with two flames at different temperatures in the optical path, the value obtained lies between the temperatures of the two flames. It therefore appears that the engine-flame temperatures reported herein lie somewhere between the maximum and minimum temperature values on the lines along which the measurements were made.

Relation to Other Work

(1) *Other Temperature Measurements in Engines.*—It is not possible to make very significant comparisons between the measurements just presented and those by other observers, because of the marked differences in the types of engines used and in the engine conditions. In general, the maximum temperature values observed by Hershey and Paton[11] and by Watts and Lloyd-Evans[12] using the sodium-line-reversal method, were lower by several hundred degrees Fahrenheit than the maximum values obtained in our engine. On the other hand, maximum temperature values obtained by Hershey[13], using a radiation method, were somewhat higher.

As pointed out previously, these earlier experimenters made observations along only one line through the engine. In the work of Hershey and Paton, the line along which measurements were made included a part of the charge which burned first and a part which burned last. Thus, their measured value at any crankshaft angle was somewhere between the maximum and minimum temperature existing in the com-

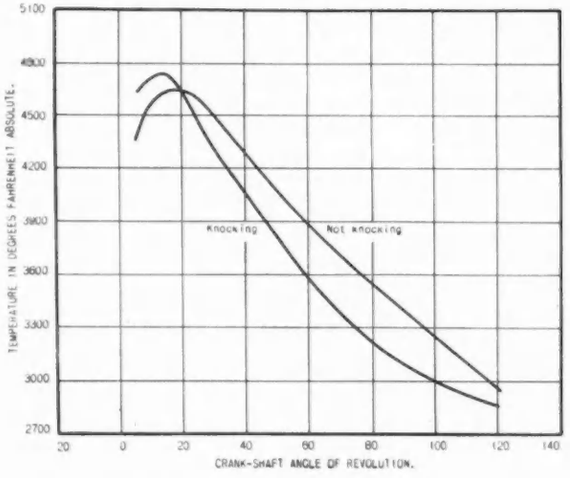


Fig. 6—Comparison of Temperatures in the Center of the Combustion Chamber under Knocking and Non-Knocking Conditions

[10] See *Proceedings of the Royal Society* (London), 1929, vol. A-123, p. 401; Griffith and Awberry.
[11] See Bulletin No. 262, University of Illinois Engineering Experiment Station, 1933; Hershey and Paton.
[12] See *Proceedings of the Physical Society* (London), 1934, vol. 46, p. 444; Watts and Lloyd-Evans. See also *Engineering*, 1934, vol. 137, pp. 362 and 743; Watts and Lloyd-Evans.
[13] See *Industrial and Engineering Chemistry*, 1932, vol. 24, p. 867; Hershey.

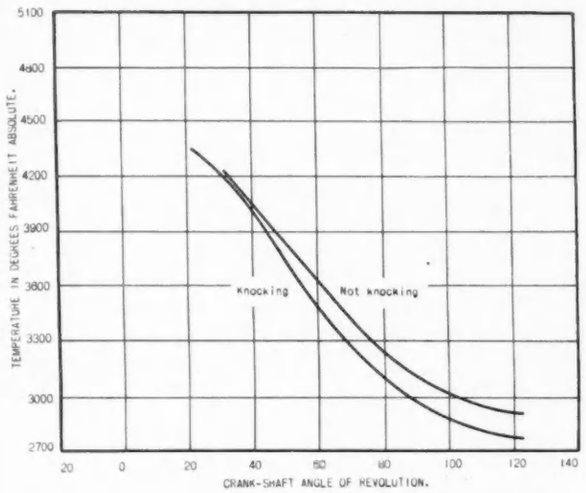


Fig. 7—Comparison of Temperatures in the Knocking Zone under Knocking and Non-Knocking Conditions

bustion chamber at that time. The arrangement of the apparatus for the work of Watts and Lloyd-Evans is not clear from their publications.

It should be emphasized here that unless it can be demonstrated that the temperature gradient is negligible, extreme caution must be exercised in carrying out thermodynamic calculations using temperatures measured in any one section of the combustion chamber. For example, Watts and Lloyd-Evans have investigated the ratio PV/T where P, V and T refer to pressure, volume and temperature, respectively, and find that it increases during the expansion stroke. On the basis of this change in the quantity PV/T they conclude that the number of molecules present in the combustion space is increasing and therefore that afterburning is occurring after the charge is completely inflamed. But until it is shown that the temperature is uniform throughout their combustion chamber, there is some doubt as to whether the value of T, as measured along one line through the gas, is significant when substituted in the equation of state. This criticism would also apply to similar calculations made with numerical averages of the present temperatures measured along three different lines through the combustion space.

(2) *Temperature Gradients in Bombs and Engines.*—Not to the writers' knowledge has a temperature gradient of the type described herein been observed previously in an engine. On the other hand, a similar phenomenon was observed in a bomb as long ago as 1906 by Hopkinson[14] who used fine platinum resistance thermometers to measure temperatures at several positions in a closed bomb of 6-cu. ft. capacity with central ignition. Under some conditions, the measured temperatures near the center were as much as 900 deg. fahr. above the temperatures near the walls. Maximum differences between the temperatures at these two positions were observed at the time of peak pressure. There appear to have been surprisingly few experimental verifications of Hopkinson's original observation, although some evidence of a temperature gradient in bombs has been obtained by David and Davies[15], Ellis and Wheeler[16], and Ellis and Morgan[17].

The explanation of the temperature gradient in a bomb, as given by Hopkinson, can be applied to the engine and is therefore included at this point. As the gas near the center of the bomb—near the point of ignition—burns, it expands against a low pressure doing work and losing energy. Subsequently, when the rest of the charge burns, the gases at the center are recompressed to approximately their original volume. Since the recompression takes place at a higher pressure than the expansion, the work done on the inflamed gas near the spark plug is greater than the work done by the gas and it gains energy adiabatically. But now consider a small mass of gas which burns last. After being compressed at a relatively low pressure, it burns and expands to approximately its original volume against a high pressure. Inasmuch as the amount of work done by the gas is greater than the work done on the gas, it loses energy. Thus, the adiabatic expansion and compression of the burning gases in a closed vessel results in an unequal distribution throughout the combustion space of the thermal energy released by combustion; and when pressure equilibrium is established, the gases which burned first are hotter than the gases which burned last.

On the basis of Hopkinson's explanation, Flamm and Mache[18] have developed a thorough mathematical analysis of the adiabatic changes during combustion in a closed spherical vessel. Very recently Lewis and von Elbe[19] have developed this theory still further in their study of explosions of ozone and oxygen in a spherical bomb. Both Flamm and Mache, and Lewis and von Elbe, claim to be able to calculate the flame velocity from a pressure-time diagram of an ideal explosion in a spherical bomb. These calculations, however, are not directly applicable to the engine because of differences in the states of the gaseous media.

Two of the most important differences between the state of the charge in the engine and that in the bomb as considered by these earlier investigators are the following:

(1) The gaseous charge in the engine is not quiescent at the time of ignition.

(2) In the engine used for this work, ignition is near an end wall of the combustion chamber; hence, the part of the charge which burns first is probably being cooled to some degree while the remainder of the charge burns. Both of these circumstances should tend to decrease the temperature grandient. The data in this paper therefore indicate: (*a*) that the heat losses to the walls by the gases which burn first are not great enough during the combustion process itself to offset the unequal heat distribution caused by adiabatic compression of these gases; and (*b*) that the turbulence of the

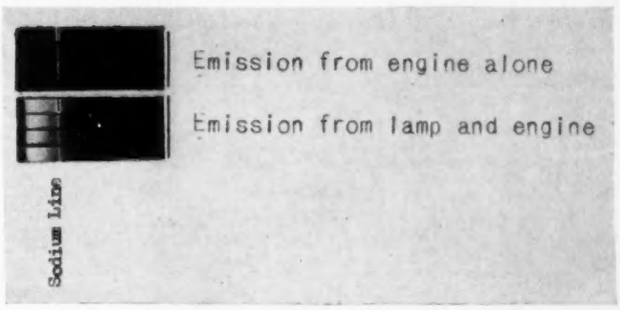


Fig. 8—Spectra Showing Self-Reversal of the Sodium Line in the Engine

[14] See *Proceedings of the Royal Society* (London), 1906, vol. 77, p. 387; Hopkinson.
[15] See *Philosophical Magazine*, 1930, vol. 9, p. 402; David and Davies.
[16] See *Journal of the American Chemical Society*, 1931, vol. 133, p. 2467; Ellis and Wheeler.
[17] See *Transactions of the Faraday Society*, 1934, vol. 30, p. 287.
[18] See *Sitz. Akad. Wiss. Wein*, 1917, vol. 126, p. 9; Flamm and Mache.
[19] See *Journal of Chemical Physics*, 1934, vol. 2, pp. 283 and 665; Lewis and von Elbe.

gases during the expansion stroke is insufficient to equalize the temperature before the exhaust valve opens.

Relationship Between the Temperature and the Luminosity of the Inflamed Gases.—It has been demonstrated by flame photography in bombs[20] and engines[21] that the gases continue to radiate light for some time after the passage of the flame fronts through the charge. Indeed, under some conditions, the visible radiation from the gases behind the flame fronts may be more intense than the emission from the flame fronts themselves.

To explain this phenomenon, the assumption is frequently made that the continued emission of light by the inflamed gases indicates the occurrence of "afterburning" in those gases. Since much confusion has arisen from loose usage of the term "afterburning," its significance in the present discussion will be defined. Herein "afterburning" will be used to denote only those oxidation reactions which are supposed to occur after the passage of the flame front and before there is established chemical equilibrium corresponding to the existing temperature and pressure. Thus, chemical reactions which result from subsequent equilibrium changes that are caused by heat losses or by variations of pressure or volume are not considered as "afterburning" according to this definition.

The emission of light behind the flame fronts is only one of a number of experimental observations which are supposed to indicate that afterburning takes place. Recently, the several more important arguments which are said to indicate that afterburning occurs have been critically reviewed by Lewis and von Elbe[22] who have concluded that no appreciable afterburning takes place when gaseous mixtures are exploded in bombs. Although their analysis of this problem is very significant in connection with engine combustion, there still exists the possibility that evidence against afterburning, as obtained by experiments with gaseous mixtures in bombs, may not apply to engines under some conditions. For example, if the charge in the engine is not completely vaporized when the flame front passes through it, the results may differ from those obtained with gaseous mixtures.

There are several interesting correlations between the present temperature measurements and some of the results established in earlier investigations which were made in this laboratory. The previous work consisted chiefly of photographic and spectroscopic studies of the visible and ultra-violet emission from the engine. A consideration of these relationships indicates that the emission of light by the gases behind the flame fronts does not result from afterburning. Most of the experiments have been performed at low or moderate engine speeds—from 800 to 1000 r.p.m.—and with mixture ratios approximating 12 lb. of air per lb. of fuel. The following pertinent observations have been made:

(1) In the engine used for this work maximum pressure is reached before inflammation is complete if knock is very light or entirely absent[23].

(2) Emission spectra show that the visible light emitted from the gases behind the flame fronts is radiated chiefly by carbon dioxide molecules[24].

(3) After the gases near the spark plug are inflamed, there is a short period before the pressure starts to rise during which time very little light is emitted. Subsequently, as the pressure rises above that due to compression, the luminosity in this region increases markedly[25]. The data presented herein show that the temperature near the spark plug likewise increases with pressure. Thus, it appears that a relationship exists between the increase of pressure, temperature and luminosity in the part of the charge which burns first.

(4) The luminosity in the inflamed gases suddenly becomes very intense at the time of knock when there is a very sudden pressure increase[25]. The data in this paper show a very rapid rise in temperature near the spark plug at this time in the cycle.

(5) Shock waves set up by the knock produce successive re-illuminations of the charge[26]. The local changes in temperature caused by these shock waves have not been measured.

(6) In general, the luminosity of the burned gases is more intense near the spark plug than at the opposite end of the combustion chamber[25]. On the basis of the temperature measurements presented herein this observation can also be explained as a temperature effect, the temperature after all the charge is inflamed being higher near the spark plug than near the opposite end of the combustion space.

The six different observations just presented indicate that the intensity of the visible and ultra-violet light emitted by the carbon-dioxide molecules behind the flame fronts is controlled by temperature and pressure. In other words, the higher the temperature and pressure are, the more intense is the radiation by these molecules. The data cited yield no information about the mode of excitation of the carbon-dioxide molecules. The stimulus may be purely thermal or it may result from molecules activated by chemical reactions which are in turn controlled by temperature and pressure. Even though the chemical equilibrium were not shifting, the amount of chemical reaction continually taking place would be great at the high temperatures and pressures existing in the engine just after inflammation. When the temperature and pressure are increased, there is not only a shift in equilibrium but there is also an increase in the amount of chemical reaction. Such reactions are not afterburning in the usual sense of the word, that is, as already defined. If afterburning is responsible for the luminosity, the rate of this reaction is slowest near the spark plug where the temperature is highest. According to reaction kinetics, such an effect on the rate of the assumed oxidation would not be expected.

The foregoing relation between luminosity and temperature is in accord with findings by David and Davies[27], who studied the emission in the photographic region and by David and Parkinson[28], who studied total radiation with a bolometer. They concluded from experiments in bombs and in an engine that the luminosity is a function of the temperature. These investigators did not relate the luminosity in various parts of the combustion chamber with local temperatures as has been done in the present research.

The temperature measurements described herein may furnish an explanation for one of the observations reported by Steele[29] in his comparison of the total radiation, which in-

[20] See *Journal of the American Chemical Society*, 1931, vol. 133, p. 2467; Ellis and Wheeler. See also Flame and Combustion in Gases, 1927; Bone and Townend. See also *Philosophical Magazine*, 1930, vol. 9, p. 390; David and Davies.
[21] See *Automobile Engineer*, 1934, vol. 24, p. 385, Rassweiler and Withrow, and p. 281, Withrow and Rassweiler. See also *Industrial and Engineering Chemistry*, 1931, vol. 23, p. 539; Withrow and Boyd.
[22] See *Journal of Chemical Physics*, 1934, vol. 2, p. 659; Lewis and von Elbe.
[23] See *Automobile Engineer*, 1934, vol. 24, p. 385; Rassweiler and Withrow.
[24] See *Industrial and Engineering Chemistry*, 1931, vol. 23, p. 769, and 1932, vol. 24, p. 528; Withrow and Rassweiler. See also *Zeitschrift für Technische Physik*, 1930, vol. 63, p. 322; Kondratjew. See also *Proceedings of the Royal Society* (London), 1933, vol. A-142, p. 362; Fowler and Gaydon.
[25] See *Automobile Engineer*, 1934, vol. 24, p. 385, Rassweiler and Withrow, and p. 281, Withrow and Rassweiler. See also *Industrial and Engineering Chemistry*, 1931, vol. 23, p. 539; Withrow and Boyd.
[26] See *Industrial and Engineering Chemistry*, 1931, vol. 23, p. 769, and 1932, vol. 24, p. 528; Withrow and Rassweiler. See *Automobile Engineer*, 1934, vol. 24, p. 281; Withrow and Rassweiler.
[27] See *Philosophical Magazine*, 1930, vol. 9, p. 390; David and Davies.
[28] See *Philosophical Magazine*, 1933, vol. 15, p. 177; David and Parkinson.
[29] See *Industrial and Engineering Chemistry*, 1933, vol. 25, p. 388; Steele.

cluded the infrared as well as the photographic region, from two windows in a cylinder head. One window was located near the spark plug and the other near the opposite end of the combustion space. Steele and co-workers found that the radiation from the window farthest from the spark plug is much less intense than the radiation from the window nearest the spark plug. On the basis of the data in the present paper, it appears that this difference is largely due to a difference in temperature in these respective regions in the combustion chamber.

In a later paper[30] Marvin, Caldwell and Steele report that the total radiation from these same two windows in the combustion chamber reaches a maximum at 25 deg. and 20 deg., respectively, after the passage of the flame front. These writers apparently believe that afterburning is responsible for the variations in intensity of the total radiation after inflammation. Alternative explanations, different for the two different points, will now be suggested.

(1) Near the spark plug, their radiation curves reach a maximum shortly before peak pressure. From the temperature measurements discussed herein, it is apparent that maximum temperature near the spark plug is likewise attained just before maximum pressure. Therefore, the time of maximum total radiation near the spark plug coincides with the time of maximum temperature and may simply be a temperature effect.

(2) The increase in radiation after the flame appears below the window in the end of the combustion chamber opposite the spark plug may be caused by delayed inflammation in the recess just under the window in their apparatus. Judging from their drawings, this cavity is about ¾ in. deep and ⅛ in. in diameter. The possible effects of such a recess at the end of the combustion chamber can be appreciated if the two following facts are considered: First, the pressure rises considerably before the flames reach the part of the charge which burns last and, therefore, an appreciable fraction of the unburned charge may be compressed into the recess below a window in this section of the combustion chamber. Second, the temperature within the recess below the window is probably lower than the prevailing temperature in the main combustion space and the rate of inflammation within this recess may therefore be considerably slower than the normal rate. Thus, what appears to be delayed burning after inflammation of the last part of the charge, may only be delayed inflammation of a portion of the charge in the recess below the observation window. It is not possible, of course, to predict either the time interval required for complete inflammation or the effect of changing from non-knocking to knocking conditions on the rate of inflammation in such a recess. But, in any case, the authors do not believe that the evidence for afterburning, as presented by Marvin, Caldwell and Steele in their study of infrared radiation, can be accepted without reservation until these alternative explanations are investigated.

Special thanks are due T. A. Boyd for his assistance and advice in preparing this manuscript for publication, and to C. F. Kettering for his continued interest in the progress of the work.

Discussion of Rassweiler-Withrow Paper

Spherical Vessel Results Applied to Engine Problems

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THE authors, Drs. Rassweiler and Withrow, are to be congratulated on the conspicuous success that has marked their researches on the explosion process in the gas engine, of which their present report is but a part. There is no doubt that their work has advanced markedly our understanding of engine phenomena.

One who has concerned himself with studies in spherical vessels where the gases are relatively stationary and where the geometry of the vessel permits evaluation of the isotherms at any stage of the combustion naturally asks himself whether the results of spherical vessel studies cannot be applied usefully to engine problems. The answer is in the affirmative, as will appear in the present discussion.

In explosions in a spherical vessel one has a rather close realization of the ideal adiabatic combustion. The maximum explosion pressure can be measured accurately and compared with the theoretical pressure. Such a comparison has meaning, since it is known that in a spherical vessel with central ignition the flame touches the wall at all points simultaneously with the attainment of maximum pressure[31] (for all but very slow explosions). The theoretical pressure can now be calculated very accurately, due to the evaluation in the last five years of precise specific heat and dissociation equilibrium data from band spectra[32]. Furthermore, one knows in detail the state of the temperature distribution during and at the end of the explosion and the quantitative effect of this temperature distribution in decreasing the maximum explosion pressure[33]. Thus, any anomalous effect is exposed by the disagreement of the observed and calculated pressures. In this way an effect which we call the *excitation lag* was found in nitrogen and oxygen molecules[34]. This effect is also observed in sound-velocity measurements, not only in O_2 and N_2 but in CO_2, N_2O, CO and Cl_2 as well[35].

It consists of the dependency of specific heats on time; that is, after combustion of the fuel-air mixture the nitrogen does not immediately acquire its complete vibrational energy but behaves more like a monatomic gas in this respect. Thus, immediately after combustion the temperature and therefore pressure are higher than one expects theoretically. A certain amount of time is required for adjustment to equilibrium among the degrees of freedom of the system which results in the acquirement of normal specific heats and consequent

[30] See N.A.C.A. 1934 Report No. 486; Marvin, Caldwell and Steele.
[31] See *Journal of the Chemical Society*, 1927, vol. 153; Ellis and Wheeler.
[32] Complete tables of these data, from room temperature to 5000 deg. cent., will soon appear. (See *Journal of the American Chemical Society;* Lewis and von Elbe).
[33] See *Journal of Chemical Physics*, 1934, vol. 2, pp. 283 and 665; Lewis and von Elbe.
[34] See *Zeitschrift Physikalische Chemie*, 1932, vol. B-19, p. 536. See also *Journal of Chemical Physics*, February, 1935; Lewis and von Elbe.
[35] See *Annalen der Physik*, 1931, vol. 11, pp. 761 and 777, and 1933, vol. 16, p. 377. See also *Nature*, 1932, vol. 129, p. 797. See also *Physical Review*, 1931, vol. 38, p. 277; Zener. See also *Naturwissenschaftliche Umschau*, a supplement to *Cheminker Zeitung*, 1932, vol. 20, p. 85; Eucken, Mucke and Becker. See also *Proceedings of the Royal Society*, 1934, vol. A-147, p. 292; Sharratt and Griffiths. For a complete list of references consult *Journal of Chemical Physics*, February, 1935; Lewis and von Elbe.

lowering of the gas temperature toward normal without loss of energy. The rate of this adjustment depends in some way on temperature and possibly pressure. The occurrence of this phenomenon having been established in spherical vessel explosions, its presence was to have been expected in gas-engine explosions, especially in view of the more rapid travel of flame in the latter.

One expects this phenomenon to play a part in experiments of the type carried out by Rassweiler and Withrow. Its effect should appear most marked in the gas at the firing end in a knocking explosion just after the knocking part of the charge has burned. The rapid burning in this part of the charge causes rapid compression of the gas at the firing end. The excitation lag occurs in this rapidly burning gas and also in the compressed gas. In the former, the abnormally high temperature and consequent over-expansion cause over-compression and abnormally high temperature at the firing end and, in the latter, the compression is so rapid as to give rise to an additional excitation lag there, with a consequent further increase in its temperature. The combination of the two amplifies the abnormal temperature peak. It is unfortunate that engine experiments do not permit the isolation of the effect of the excitation lag, which contributes to the difference between the peak temperatures in knocking and non-knocking explosions. Rassweiler and Withrow point out correctly that one of the contributors to this difference is the greater heat loss through the engine walls before inflammation is complete in non-knocking explosions. It is not unreasonable to suppose that the excitation lag is as important a contributor to this temperature difference as heat losses.

Another phenomenon accompanying knocking explosions, namely, severe gas vibrations, is augmented by the excitation lag. In spherical vessel explosions where no knocking occurs these vibrations have been attributed to the excitation lag[36]. They are assumed to be induced by the rapidity of the volume contraction as the energy adjustment among the degrees of freedom takes place. In the engine this effect would be superimposed on the mass movement of the gases caused by the rapid burning in the knocking part of the charge. Which contributes more to the gas vibrations is difficult to say. Rassweiler and Withrow's proposal that the rapid vibrations or mass movements of the gases are responsible for the observed greater heat loss by increased heat transfer to the jacket at once satisfactorily explains the power loss which is observed during knocking explosions. Contrary to rather general opinion this problem was not a simple one. One knows now how the facts are correlated; namely, in a knocking explosion heat is transferred to the walls at a greater rate, consequently the exhaust gases are cooler. Since thermal radiation has been found to play little or no part[37] in this increased rate of heat transfer in knocking explosions, there remain gas vibrations and, to a lesser degree, higher gas temperatures as the only possible causes. Thus, the excitation lag plays a part in one of the most important phases of the knocking problem.

Furthermore, due to the increase in specific heats with time, the effect of the excitation lag is to tend to increase the slope of the cooling curve in knocking explosions.

The latter part of Rassweiler and Withrow's paper is concerned with a discussion of afterburning in connection with luminosity. Elsewhere, we have discussed this subject from several points of view in considerable detail[38]. Here, only the general conclusions will be given. Rassweiler and Withrow show by detailed argument that the luminosity is simply the thermal radiation of the products of combustion. This is in agreement with earlier conclusions[39]. Their discussion, however, does not entirely meet the contention of David and co-workers[40] in England who claim to have uncovered another type of so-called afterburning in the form of latent energy stored up in long-lived abnormal molecular products of combustion. David believes the retarded luminosity to be the temperature radiation of these abnormal molecules and offers as support the statement "it is well known that gases like CO_2, H_2O, N_2, etc., in their normal condition when heated by external means to temperatures such as inflamed gases have in these (his) experiments[43] remain dark." It is quite evident, however, from a perusal of the literature, that nobody has ever heated CO_2, H_2O, H_2, N_2, etc., externally to temperatures ranging from 1800 to 3000 deg. cent., which are the temperatures of the gases in the hot central core of the spherical vessel, and made luminosity observations. The temperatures at which such observations have been made are those at which gases formed in flames also remain dark.

An approach to the problem of afterburning in this enlarged sense by engine experiments is rendered impossible by inability to compare correctly the experimental and theoretical temperatures or pressures at any stage of the explosion. It may suffice to state here that the comparison of experimental and theoretical explosion pressures in a spherical vessel and flame temperatures in stationary flames shows conclusively the absence of any form of afterburning[42]; that is, not only no further oxidative reaction (beyond equilibrium conditions at the existing temperature) behind the flame front, but also no latent energy in the form of the postulated stable abnormal molecules. The experimental pressure measurements of David and co-workers themselves, when treated correctly, are in general agreement with those of numerous other investigators in disproving the afterburning hypothesis[42]. Thus, afterburning, an hypothesis first put forward by Dugald Clerk, has not only never been demonstrated but has been disproved. I would warn against the use of this hypothesis in combustion problems. To quote one instance, as correctly pointed out by Rassweiler and Withrow, the existence of unburned gas in the corners of the combustion space when maximum pressure is established in normal combustion has been confused with afterburning.

Concerning the line-reversal method for measuring flame temperatures, David[44] recently has questioned its validity, stating "the sodium line-reversal method often, perhaps generally, leads to temperature determinations much in excess of the true flame temperatures which are proportional to the mean molecular translational energy of the flame gases". The arguments on which this was based have been shown[45] to be partly erroneous and partly unconvincing.

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[36] See *Journal of Chemical Physics*, February, 1935; Lewis and von Elbe.
[37] See N.A.C.A. 1934 Report No. 486; Marvin, Caldwell and Steele.
[38] See *Journal of Chemical Physics*, 1934, vol. 2, p. 659; Lewis and von Elbe. See also *Philosophical Magazine*, in print. See also *The Engineer*, in print. See also *Journal of Chemical Physics*, February, 1935; Lewis and von Elbe.
[39] See *Journal of Chemical Physics*, 1934, vol. 2, p. 659; Lewis and von Elbe. See also *Philosophical Magazine*, in print. See also *The Engineer*, in print. See also *Journal of Chemical Physics*, February, 1935; Lewis and von Elbe. See also *Philosophical Magazine*, 1930, vol. 9, p. 402; David and Davies.
[40] See *Philosophical Magazine*, 1930, vol. 9, p. 402; David and Davies. See also *Philosophical Magazine*, 1934, vol. 17, p. 172, and 1934, vol. 18, p. 228; David and Jordan. See also *The Engineer*, 1934, p. 558; David.
[41] See *The Engineer*, 1934, p. 558; David.
[42] See *Journal of Chemical Physics*, 1934, vol. 2, p. 659; Lewis and von Elbe. See also *Philosophical Magazine*, in print. See also *The Engineer*, in print. See also *Journal of Chemical Physics*, February, 1935; Lewis and von Elbe.
[43] See *Philosophical Magazine*, in print.
[44] See *Engineering* (London), 1934, vol. 138, p. 475; David.
[45] See *Engineering* (London), in print; Lewis and von Elbe.

(1) The fact that thallium salts give low measured flame temperatures is entirely in accord with the theory of the method, since thallium does not possess a true resonance line.

(2) David's method for measuring flame temperatures is basically unsound.

(3) The higher-than-theoretical flame-temperatures found for certain mixtures need not be attributed to a fault of the method or experimental error. These have been accounted for by the excitation lag.

On the other hand, the physical principle of the line-reversal method is sound, and there is sufficient agreement with other well-founded methods to put the line-reversal method beyond question.

Comments on Temperature Gradient, Thermodynamics, and Kindred Subjects

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THE authors are to be congratulated on carrying out an additional investigation of combustion phenomena in a gasoline engine in their usual thorough and competent manner. By no means the least valuable aspect of their extensive data on engine combustion is that the major portion has been obtained with the same engine under strictly comparable conditions. The factors affecting combustion in any one engine are so numerous and difficult to control that the reproduction of experimental conditions is one of the most annoying problems confronting the investigator. This difficulty is increased manifold when it becomes necessary to correlate data taken by several investigators on different engines and under different conditions. Hence, while the authors' well-known investigations of flame movement, pressure fluctuations, and emission and absorption spectra are each in themselves valuable, collectively with the present investigation of temperature, they constitute the outstanding contribution to the study of combustion in an engine.

Of particular interest is that portion of the paper dealing with the temperature gradient existing in the gases in the combustion space. Such temperature gradients have been the basis of speculation for some time, but their actual existence and magnitude have now been determined. However, the important thing is not that they exist, but that they are relatively small. From the curves in Figs. 3 and 4, the maximum temperature difference between the firing end and the center for non-knocking and knocking conditions are seen to be 150 deg. and 300 deg. fahr., respectively, while the differences for the extreme ends under the same conditions are 400 deg. and 600 deg. fahr., respectively. These differences correspond to temperature gradients between 100 and 150 deg. per in. and are probably the upper limits for an engine of these dimensions, since the combustion chamber has a large surface-to-volume ratio and the direction of the gradient is the same as that of the flame movement.

The criticism of thermodynamic calculations based on temperatures obtained by line-reversal measurements does not appear to be serious. As the authors state, Griffith and Awberry have made temperature measurements with two stationary flames at different temperatures in the optical path. They report that, with the lower temperature flame adjacent to the spectroscope, the observed temperature falls between the two flame temperatures and approximates the arithmetical mean of the two. Hence, in determining flame temperatures in an engine, if the flame is advancing along the optical path within the region of low temperature adjacent to the spectroscope, the observed values should be fairly representative of the average temperature throughout the region. Thus, line reversal measurements are apparently the result of an effect integrated throughout a region of the combustion chamber. By contrast it should be mentioned that thermodynamic calculations are based on pressure measurements made in a limited region close to the surface of the combustion chamber. Such measurements can scarcely represent conditions throughout the region during inflammation, yet they are used with little or no question. Have the authors made any attempts to measure the pressure simultaneously at several points around the combustion chamber using carbon-stack type indicators? Hunn and Brown[46] have found pressure gradients in a cylindrical bomb during combustion and similar measurements on an engine should be of value.

The discussion of temperature and luminosity is also of considerable interest. One of the most surprising results of the authors' investigation is the very slight difference in temperature of the gases in the knocking zone under knocking and non-knocking conditions.

During the radiation investigation[47] some few measurements were made under knocking conditions which indicated that the radiation emitted when knock occurred was much more intense than that emitted with non-knocking conditions. For example, while the maximum thermopile galvanometer deflection for normal combustion was 12.9 cm., with even moderate knocking the maximum deflection increased to 20.5 cm. It was for this reason that the radiation method of temperature measurement was abandoned in favor of the line reversal method. At the time it seemed probable that some of this increase in intensity might be due to increased temperature, but to attribute all of the increase to temperature alone would necessitate impossibly high temperatures. The alternative explanation that the increased intensity was principally due to luminescence was accepted and since no ready means of correcting for this effect was available the method was discarded in favor of the line reversal method. Such increase in radiation intensity with knocking conditions has also been reported by other investigators[48]. An increase in radiation intensity without a corresponding increase in temperature as measured by line reversal would seem to be convincing evidence that the excitation of the sodium atoms in the flame is thermal and hence that temperature measurements made by line reversal are independent of luminescence effects. This criticism of the method has been recently advanced by David[49].

[46] See *Industrial and Engineering Chemistry*, 1928, vol. 20, p. 1032.
[47] See *Industrial and Engineering Chemistry*, 1932, vol. 24, p. 867; Hershey.
[48] See S.A.E. JOURNAL, 1924, vol. 14, p. 182; Midgley and McCarty. See also N.A.C.A. 1934 Report No. 486; Marvin, Caldwell and Steele.
[49] See *Engineering* (London), 1934, vol. 157, p. 558.

Formation of H_2O and CO_2 and Burning Within a Cavity Basis of Comment

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—Frank R. Caldwell
—Sydney Steele
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WE have read the paper with much interest but feel that it is worthy of more careful study than we have as yet been able to give it. Our present comments are therefore confined to the references which are made at the end of the paper to our own experiments.

The authors of the paper attribute the rise in temperature of the inflammed gases near the spark plug to the compression of these gases as the pressure in the cylinder increases, and suggest that the coincident rise in the total radiation, which we found in experiments at the Bureau, is due simply to this temperature rise. However, it must be realized that the total radiation is a function of the temperature, not of the inert constituents of the charge, but particularly of the CO_2 and H_2O, and that it is affected by the concentration of these substances and perhaps their "chemical condition" as well as their temperature.

It seems reasonable to suppose that H_2O and CO_2 are formed by combustion at temperatures far above those attained by inert portions of the charge—including any sodium vapor—that in this newly formed state they radiate most intensely, but that they are rapidly cooled and their potency as radiators diminished as they are called upon to heat about three times their volume of inert constituents. Thus, if the final products H_2O and CO_2 were suddenly formed in large quantities within a narrow flame front, we would expect to find there a zone of very intense radiation followed by a region in which the recompression of the charge, while raising the average temperature level, would only partially offset the cooling of the H_2O and CO_2 as they transferred heat to the inert materials. Since the observed rise in radiation was not sudden, but gradual and long continued after the arrival of visible flame, we infer that the formation of H_2O and CO_2 is also gradual, although we point out in our paper that the recompression and the movement of more recently burned charge into the neighborhood of the spark plug probably prolongs the rise in radiation in this region.

In connection with the possibility of burning within the cavity beneath a window, the small spacing collar below each window was made of nickel and designed to facilitate rapid cooling within the cavity. That it accomplished this purpose with some success was evidenced by the fact that the fluorite windows cracked, presumably due to heating, when the spacer was removed and the fluorite placed close to the combustion chamber.

In the normal run the flame arrives under the last window at about the time of maximum pressure. It seems unlikely that it would propagate far into the cavity against the stream of gases which flows outward at an increasing rate as the pressure in the cylinder drops. Even in the knocking run, where the flame probably is driven into the cavity by the sharp rise in pressure accompanying the knock, there is little evidence of prolonged burning in the cavity. While admitting that burning in the cavity may influence the results and introduce some uncertainty in their interpretation, we do not believe that this burning dominates the observations to the extent suggested.

Authors Analyze Important Points in the Discussion

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Lloyd Withrow
General Motors Corp.

REGARDING the possible inequality of pressure throughout the combustion chamber, as suggested by Hershey and Paton, there appears to be no evidence of appreciable pressure gradients under non-knocking conditions. However, it is now quite well established that a severe knock sets up violent pressure waves which travel back and forth through the gas in the combustion chamber; in some cases, as much as 45 deg. of crankshaft revolution is required after the occurrence of knock for pressure equilibrium to be established.

Turning now to the comments of Marvin, Caldwell and Steele, we do not feel that their remarks affect our principal contention regarding their work; namely, that in view of our temperature measurements, their published observations of total radiation do not constitute proof of afterburning.

The fact cited by Marvin, Caldwell and Steele, that they did not observe a sudden increase in radiation upon the arrival of the flames, would be expected in an observation integrated over a number of explosions even though, in a single explosion, the actual increase in radiation from any point in the combustion chamber upon the arrival of the flames was abrupt. Careful consideration of the following facts will make this point clear; (*a*) the window has a finite size, (*b*) the observations extend over a finite angle, (*c*) the charge beneath the window has a definite depth and all the gas along a given line does not inflame simultaneously, and (*d*) the position of the flame front at a given angle varies from explosion to explosion so that after the earliest flames first appear under a window there is a lapse of time before all the charge under the window is completely inflamed in every explosion.

If we interpret the third paragraph of their comments correctly, they state that, if CO_2 and H_2O were suddenly formed in a narrow zone, one would expect that while the gases near the spark plug were being recompressed and the average temperature level raised, the temperature of the newly formed H_2O and CO_2 might actually be decreasing. This statement infers an appreciable time lag in the transfer of translational energy from CO_2 and H_2O molecules to the inert-gas molecules. But calculation shows that in 1 deg. of crankshaft revolution—with an engine speed of 1000 r.p.m.—each newly formed CO_2 molecule undergoes an average of approximately 1,000,000 collisions with nitrogen molecules. Inasmuch as translational energy is very readily transferred by collision, it is most unreasonable that there should be a lag of anywhere near one crankshaft degree in the equalization of temperature of inert and active constituents. However, it might still be argued that radiation depends upon the energy partitioned among the internal degrees of freedom and that the newly formed CO_2 and H_2O molecules might be very slow in giving

(Continued on page 146)

The Winter Operation of Aero Engines

By Alan Ferrier
Royal Canadian Air Force

THE author describes the conditions of aircraft operation in Canada during the winter and after outlining the laborious technique pursued for several years emphasizes the need for improvement in lubrication and starting technique in order that commercial undertakings may make full use of the short northern day.

Elimination of cold weather lubrication difficulties is based on the proposition that oil temperature is in itself immaterial and that its only real importance is the effect on viscosity which is regarded as a *state* rather than as a *property*. In consequence a variation of oil grade and a premeditated variation of oil operating temperature under adequate control is advanced as the solution and the results of two years practical trial are offered as proof. A brief specification of a desirable oil system is given, together with a forecast of possible developments in the near future to deal with existing lubricants.

Cold oil having been proved to be effective down to temperatures of —25 deg. fahr., extension to lower temperature ranges again brings to the fore the problem of obtaining the first ignition. The use of booster devices for the ignition in conjunction with special starting fuels is contemplated and briefly discussed. The necessity for engine warming equipment cannot be ignored for some time and desiderata for this are submitted.

Lubrication of valves, and valve gears, requires attention. The lubrication of accessories such as starters is a big problem in itself.

Difficulties in connection with ice in the carburetor are, if anything, rather less severe in Canada than in the warmer but damper regions further south.

ALTHOUGH the author is an officer of the Royal Canadian Air Force, this paper deals only very incidentally with problems peculiar to military aviation. The control of civil aviation in Canada is vested in the Minister of National Defence and the members of the Aeronautical Engineering Division of the Department of National Defence are in close touch with civil aviation whether operated by the Government or by private enterprise.

That a clear idea may be gained of the particular problems confronting the operator in Canada it is necessary first of all to describe briefly the fundamental characteristics of most Canadian flying. It is essentially a pioneering activity. All commercial undertakings of whatever nature are designed to fill a need—and the less competition the better. One of Canada's crying needs was better facilities for communication in the immense areas of undeveloped territory to the north of the main transcontinental railway lines. The airplane just naturally slipped in to fill this need in competition against the canoe and dog team rather than entering into the expensive development required to compete against the well organized and efficient East-West communication systems.

Transcontinental aviation is not by any means being ignored but the great bulk of activity is now and will for some time remain in the bush and wilderness territory, and a vast majority of customers is among those whose enterprises are of the pioneering sort such as mining corporations, prospectors, timber cruisers, surveyors, fur traders and so on. The very nature of the operations implies mobility and flexibility and consequently the establishment of elaborate bases is impossible. The home base may be moderately comfortable, although it may itself be some hundred miles from the nearest railway, but the outer terminus will as likely as not be a sand bar or beach or a flat patch of snow in the lee of some sheltering trees or rock. Under these circumstances every airplane must be self-sufficient and must carry all the equipment necessary for its own service and maintenance. It must also carry emergency rations and clothing and fuel for the preservation of the lives of its occupants in the event of a forced landing. It is obvious that the necessity for inflicting all this weight on the poor flying machine makes serious inroads on its pay load.

When winter flying operations started seriously in Canada shortly after the World War, the technique at the commence-

[This paper was presented at the Annual Meeting of the Society, Detroit, Jan. 15, 1935.]

ment and at the termination of a flight was terribly laborious. The author's chief, Group Captain Stedman, R.C.A.F., vividly describes the efforts to start a four-engined Handley Page bomber in quite moderately cold weather in Nova Scotia. He tells of hordes of assistants "chain-ganging" buckets of boiling water into the radiators until the outlets on the far end of the water manifolds ran hot; of pouring hot oil into the tanks; of warming at least 48 spark-plugs on a shovel over a fire and then putting them in; and of the fourth engine sulking and the other three having to be shut down for fear of overheating on the ground; and then of starting the whole process over again. The heartrending thing was that with one engine running its available horsepower could not be harnessed to start the other three. Later, at a Government air station at High River, Alberta, where Liberty-engined D.H.4's were in use, a volatile anti-freeze was employed and each aircraft was fitted with an elaborate still for the recovery of the anti-freeze and its subsequent return to the radiator. The coming of the aircooled radial engine certainly reduced the difficulties, but even at that they remained very formidable. Oil had to be drained from motor and tank with the engine still running, a risky and most undesirable process. Then it had to be heated all over again and poured into the tanks before the commencement of the next flight, with some likelihood that by the time the motor actually started the oil had become cold and the first few moments of running were done with little or no lubrication.

To ensure a start it has been and still is the practice to warm the motor by encasing it in a heavy canvas cover or a nose tent supported on the vertical propeller and applying heat under the cover by means of a blow lamp, gasoline stove, or even a wood-burning stove. This process takes from half an hour to an hour and the cover has to be removed before an attempt is made to start. The oil was poured in at the last possible moment. If for any reason the engine refused to start the whole process of draining and reheating the oil, replacing the engine cover and warming the cylinders had to be repeated. The mere manhandling of 50 to 100 lb. of oil with its container, and of the heavy bulky engine cover is a labor not to be despised and by the time an aircraft is ready to take off, the crew has already done a goodly part of a day's work and, if it is required to take full advantage of the short daylight hours, a great proportion of the preparatory work and the after-flight work has to be done in the dark. The weight and bulk of the oil containers, engine warming bag or tent, and stove are formidable and if the operation is in a treeless district, such as the barren lands of the Northwest, the difficulty is increased by the necessity for carrying fuel for warmth as well as fuel for power. Incidentally, leaded fuel is not suitable for burning in stoves so special fuel in separate containers must be carried.

For several years these arduous conditions were accepted as the inevitable accompaniment of winter. This sounds like rather a weak admission, but Canadian aviation has no great resources either in spare cash or in engineering personnel to devote to experiment and research and we were for some time quite fully occupied with winter landing gears and allied problems. Commercial operators were busy trying to survive and, having settled on a workable technique, had little time or money to devote to research which was not immediately productive.

Attack on the Lubrication Problem

The urge to reopen the attack on the engine problem arose only a few years ago and came to this individual in a manner which may be worth relating. One trouble encountered was that the oil temperature could never be worked up to the degree recommended by the engine manufacturers. This was countered by an elaborate system of lagging pipes and tanks, shielding crankcases and plugging up all sorts of cowling openings. This involved a great deal of work which had to be done every fall and undone again every spring, and, from some over-worked maintenance man, the suggestion arose that the lagging and so on be retained as a permanent feature and that large oil coolers be fitted to look after summer requirements. This was too much like asking a man to wear his winter overcoat all the year round and to carry an ice pack with him for relief when needed. One's gorge rose in sympathy for the poor overloaded airplane. The objectionable suggestion contained, however, the germ of an old idea and after considerable thought and discussion the Department proceeded to put it to work—in reverse.

Why not work a step or a couple of steps lower on the temperature scale, and use oil coolers in *winter time* to make sure that we remain on the chosen step? After all, a given quantity of fuel burning with a given quantity of oxygen will produce approximately the same amount of heat no matter what the original temperature of the oxygen. Some of this heat is converted into useful energy, a good share is dissipated to the atmosphere through the cylinder walls, directly or through a cooling liquid, some more goes away with the exhaust and a fair proportion is imparted to the oil and thence to the atmosphere. The atmosphere therefore acts as a direct cooling medium for a very considerable proportion of the dissipated heat and, though the exhaust gases will probably be at much the same order of temperature summer and winter, it is quite reasonable to suppose that the general temperature level will be lower in winter than in summer. This supposition is definitely supported by the existence of elaborate shutter systems installed with the sole idea of keeping the temperature up. Any one who has shovelled coal into a furnace during a Northern winter can argue this out for himself.

The next supposition is admittedly assailable. Here it is: "If an oil has the proper 'oiliness' and all its other physical and chemical properties are satisfactory, then the physical characteristic which finally determines its suitability as a lubricant under a certain set of conditions is viscosity. Furthermore, viscosity should be regarded as a *state* rather than as a *property* because it varies with temperature."

If this proposition is accepted then a 63 sec. oil at 120 deg. fahr. is in the same *state* and therefore has the same lubricating qualities as a 120 sec. oil at about 165 deg. fahr. (See Fig. 1.) If the viscosity indices of the oils are of the same order, then the same deduction could be made if we add a couple of hundred degrees of temperature to each side. The weak point of the chain comes right here.

Is the temperature rise of a 63 sec. oil entering an engine at 120 deg. fahr. and working in winter of the same order as the temperature rise of a 120 sec. oil entering the engine at 165 deg. fahr. and working in summer?

Basing our opinion on the established fact of a lowered general temperature level we in Canada decided the point was well worth putting to the test.

Fortunately for our requirements a Wright R975E engine had just completed full type trials for a Type certificate of airworthiness on the test dynamometer of the National Research Council of Canada. The engine had been carefully calibrated for power and had then been torn down, very thoroughly inspected and "miked," and then reassembled for

use. Its exact condition, therefore, was well established. This engine was installed in a Bellanca Pacemaker fitted with a controllable oil cooler and with the usual run of measuring instruments for a test of this nature. The aircraft was operated for 200 hr. during the winter of 1932-33, observations being made of consumption of fuel and oil, cylinder head temperature, oil pressure, inlet temperature, and all relevant conditions which might have significance; 75 and 63 sec. oils were used and no mercy was given, the aircraft doing a considerable number of full throttle climbs. At the end of the 200 hr. period, and incidentally of the winter, the engine was removed from the Bellanca and put on the dynamometer where the power was calibrated again, after which a complete stripping, inspection and "miking" was done. The results, an abstract of which is contained in Appendix I, were sufficiently encouraging to warrant further trials the next winter. Consequently, arrangements were made to fit several aircraft, powered by Pratt & Whitney, Wright and Armstrong Siddeley engines, with the necessary oil coolers, and service trials were done by pilots untrained to test work performing ordinary service functions. No unusual trouble was experienced and we felt satisfied that a lot of the grief of winter flying was being eliminated and that the engines were certainly getting their oil during the first few revolutions—which was a matter of considerable doubt in the old days.

Last winter a Rolls-Royce Kestrel was tackled. This was a different proposition altogether as, being a liquid-cooled engine and the aircraft being fitted with a controllable radiator, the cylinder temperature should be the same winter or summer. To be strictly consistent, the cooling liquid temperature should have been stepped down to a lower figure than that used with the summer oil, but this was not done. The airplane was left exposed out of doors all winter and was started up every day, a number of dead cold starts being effected with no great difficulty at sub-zero temperatures down to as low as —20 deg. fahr. No real trouble was encountered.

As a result of all this experimentation, the Department felt that the right track was being followed, especially as the automobile industry seemed to be thinking along much the same lines. Consequently, a Technical Memorandum was published to impart to commercial and private operators the benefit of our experiences. This memorandum, which was written mainly for operators and maintenance men, is contained in Appendix II.

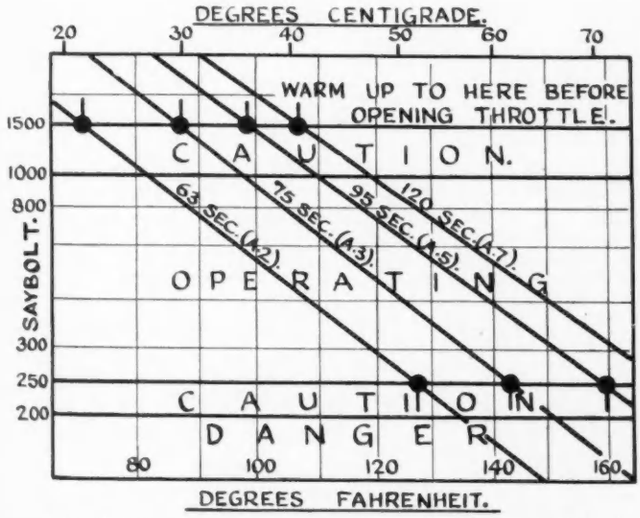


Fig. 1—Viscosity-Temperature Chart. Posted in a visible position on every aircraft in the Royal Canadian Air Force

Installation of the lubrication system in an aircraft required to operate in widely varying climatic conditions should include an oil tank or tanks well protected from such external influences as warm air from the cylinders or the cold external atmosphere, and also should include a generous controllable oil cooler in the scavenge line. It is quite a good idea to have the oil feed and return pipes enter the oil tank within the confines of a central enclosure dividing off a gallon or so of oil in the middle of the tank. This enclosure must have feed holes communicating with the main body of oil in the tank, and, if desired, a manually operated bypass in the scavenge line can be arranged to return to the outer section of the tank. The bypass cock must in no position close off both return passages. When the motor is started up, the central body of oil is warmed much more rapidly than would be the whole body in a simple tank and consequently the proper lubrication is effected at an earlier moment. This definitely saves on running up time and on wear and tear at the start.

The oil cooler should bear the whole responsibility for the oil temperature and should therefore be of sufficient capacity to permit overcooling on the hottest summer day. Conversely, if it is completely cut out, overheating should occur on the coldest possible winter flight. Only in this way can the pilot have complete control throughout the four seasons without resort to seasonal modifications, such as shutters and lagging. Thermostatic oil temperature control would be quite satisfactory provided that the thermostat can be set to the correct temperature for the particular grade of oil being used. Our experience with aircraft having common types of air-cooled radials up to 425 hp., and controllable oil coolers is that 63 sec. oil remains fluid at —20 deg. fahr. and can safely be used up to an atmospheric temperature of 32 deg. fahr. and that 95 sec. oil is satisfactory for the upper range except for really abnormal hot weather. Three grades of oil ought to cover the whole year north of the 40th parallel.

Admittedly, people who operate North-South air lines from the 40th to the really low parallels will have to think a bit, but that worry can be left to them. As the development has only been carried down to —20 deg. fahr. for cold oil starts, and aircraft are quite consistently operated at between —60 and —70 deg. fahr., the necessity for really rapid oil drainage has not been eliminated. Consequently the drain cock and pipe should be of generous proportions, very easily accessible and should discharge vertically downwards when the aircraft is resting normally on the ground so that there is no necessity to keep on moving the can as the head decreases. The oil filler arrangements should likewise be very large and easily reached. One can't get people to filter oil at —40 deg. fahr. nor do they want to stand pouring oil out of a can above their heads or in a cramped position at that sort of temperature. The same remarks apply to refueling arrangements but to a lesser degree. To be really safe, filters should be oversize and the oil filters should be duplicated, one on the inlet and one on the scavenge pipe. Great care is required in locating the oil temperature thermometer if provision has not already been made by the engine manufacturer for a thermometer pocket. The measuring element of the thermometer must be well surrounded by the moving stream and must not be in a pocket or back eddy, because quite serious errors of temperature measurement may occur. The present instruments for supervision of the oil condition are the thermometer and the oil pressure gage. It has been suggested that, as viscosity is

the real criterion, a viscometer should be included in the system. Investigations now are under way at the National Research Council laboratories to determine whether a viscometer can be made to tell the truth and, if so, whether the information is of value, and whether the instrument can be used to replace the thermometer and pressure gage.

Engine and Oil Warming

Three general types of shelters for engine warming have been in general use in Canada: (1) the engine cover, (2) the nose tent, and (3) the nose hangar. The first two are completely mobile while the third is semi-mobile in that it can be knocked down and transported by air if it is found necessary to move a sub base.

The engine cover (Fig. 2) is merely a bag tailored to fit as closely as possible round the engine, vented at the top and provided with a sort of trunk or flue at the bottom into which the chimney of some heating device can be inserted. The bag does not cover the airscrew. Its main drawback is that no maintenance work can be done on the engine while the bag is in place.

The nose tent (Fig. 3) is merely a wigwam shaped affair supported on the tip of one blade of the airscrew and laced around the body of the aircraft. It is usually made of two ply of durable, close-woven canvas. The heating element is placed right inside the tent, provision being made for air inlet and venting. The skirt is spread out and held in place by snow piled on it. The nose tent is necessarily heavier than the simple engine cover, but has the advantage that a limited amount of servicing and maintenance may be performed under it and, in emergency, its shelter may be used for human beings.

The nose hangar (Fig. 4) is a collapsible framework of light metal tubing covered with canvas. It is built of sufficient height to permit turning the airscrew and a split curtain is laced tightly round the body of the aircraft behind the engine. This equipment permits the execution of field maintenance work to the fullest degree but is not intended to be carried as part of the routine winter gear of the aircraft. It is mounted on skids or skis to facilitate placement.

Where supplies of wood may be obtained, use is made of a sheet metal stove for warming purposes, but the most usual source of heat is gasoline burnt in a Primus stove or plumber's pot suitably shrouded and flued to take the heat where it will do the most good. As mentioned previously, leaded fuels are not good to burn in these stoves and are definitely forbidden for cooking. Hence a supply of special fuel in separate containers has to be carried. The heat from a large gasoline burner is quite fierce and precautions should be taken to avoid damage to soldered radiators and other

Types of Shelters for Engine Warming in Use in Canada

Fig. 2—The Engine Cover is a bag tailored to fit as closely as possible around the engine

Fig. 3 — The Nose Tent is a wigwam-shaped unit supported on the tip of one blade of the airscrew and laced around the body of the aircraft

Fig. 4—The Nose Hangar is a collapsible framework of light metal tubing covered with canvas.

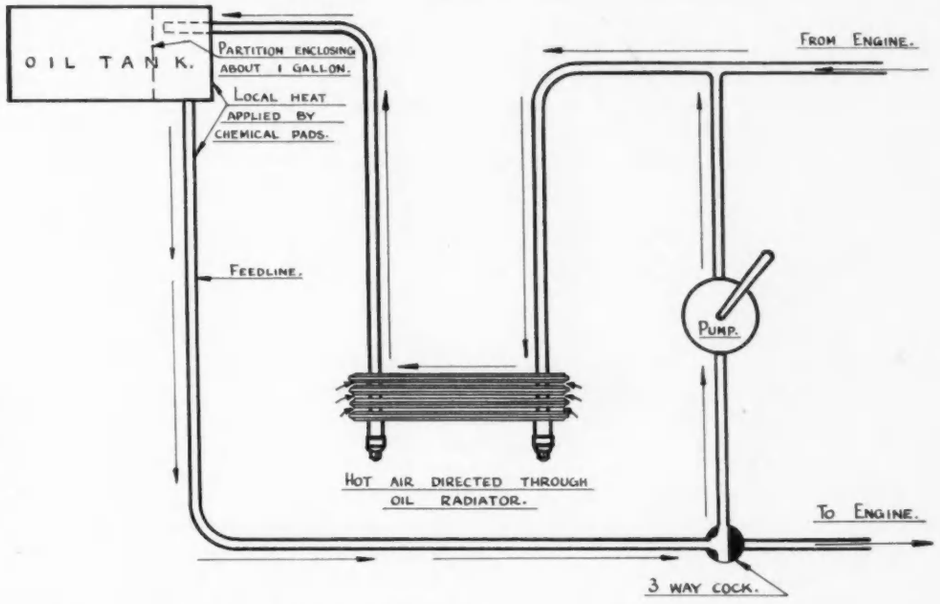


Fig. 5 — Suggested method of warming oil in cold aircraft engines on which Canadian National Research Council has made preliminary investigations.

vulnerable items, and to avoid danger of fire by providing some sort of control, preferably an automatic one by thermostat. This is most applicable in the case of the simple engine cover and where the metal flue enters the bag, a non-inflammable connection with asbestos is essential.

None of these equipments make satisfactory provision for warming the oil. On many aircraft the oil tank is situated behind the fire bulkhead and this adds to the difficulty. All sorts of attempts have been made to overcome the trouble. One of these which has some merit is the introduction of a water boiler in the flue of the stove. Steam can then be led through flexible piping to an immersion heater thrust into the oil tank through the filler neck. This is not very efficient as oil does not warm up readily in bulk from a local source of heat. An improvement might be effected by using a built-in steam heating element of efficient design with very thin, closely-spaced fins.

Another suggestion for which a preliminary investigation has already been made in the laboratories of the National Research Council is as follows: The oil tank to be fitted with an internal pierced enclosure surrounding about a gallon of oil as mentioned before but located so that an accessible portion of the outside wall of the tank forms one side of the enclosure, the feed and scavenge pipes to lead through this portion of the wall, and finally a hand pump and three-way cock is to be fitted on a bypass pipe short circuiting the motor as close as possible to the inlet and outlet connections. (See Fig. 5.) The application of local heat by means of chemical pads, such as the "Thermat" pad made by Bauer & Black, applied to the outer wall of the tank will raise the temperature of a portion of the oil sufficiently to permit it to flow when the hand pump is operated. If in the meanwhile heat from the apparatus which is being used to warm the motor is conducted through the oil radiator, sufficient warm oil for a safe start may be accumulated in a reasonable time without any need to drain the oil, which is one of the main bugbears of the winter operator. The weight of the extra piping, pump and "Thermat" pads may be balanced against the eliminated oil container and the extra fuel required to warm the oil separately. The feasibility of this process has been demonstrated, but practical trials have not yet been made, though it is the Department's intention to make such trials this winter. It will of course occur to every one that the steam immersion heater idea could be applied to this process, thus making one independent of chemical pads.

Ignition and Starting

Getting the first kick out of the engine is a ticklish problem and has been the subject of numerous experiments. An organized attack on the problem was commenced under the auspices of the Air Research Committee of the Research Council of Canada by Prof. C. H. Robb of the University of Alberta at Edmonton in 1920. Professor Robb continued his experiments for about three winters and forecasted several developments which only now are really being put into practical use, in particular the use of an oil cooler in winter. He used a Liberty engine and the problem was presented to him in this way: "The engine is in an airplane forced to spend a night in the open away from a base. It has been assumed that while the engine was still hot the cooling system has been drained or that an efficient antifreeze mixture is available. It is also assumed that the battery has been removed from the machine and kept at ordinary room temperature and that a supply of commercial ether is available."

Some of Professor Robb's technique would be objected to today as being too brutal. For instance, he recommended suppling the engine by injecting about ½ pt. of gasoline and turning the crankshaft over with switches off until the engine worked freely. In extenuation it must be remembered that the starting handle of a Liberty engine took some pretty heavy heaving to get results. The following table gives his recommendations:

Temperature	Gasoline Per Cent	Ether Per Cent
20 deg. fahr. and warmer	100	Nil
0 deg. fahr. to 20 deg. fahr.	75	25
—15 deg. fahr. to 0 deg. fahr.	66	34
—30 deg. fahr. to —15 deg. fahr.	50	50
Below —30 deg. fahr.	Nil	100 (warm)

About ¼ pt. of the appropriate mixture was injected into the intake manifolds and as soon as the engine kicked an additional ¼ pt. was shot in. This generally sufficed for the engine to begin to feed on gasoline from the carburetor which had in the meanwhile been flooded. Large capacity priming pumps and nozzles were found to be essential.

It will be noted that under the conditions it was assumed that the battery could be kept at room temperature. This is a concession that we would not care to allow today as the object is to eliminate all possible manual labor. The loss of capacity of storage batteries at low temperatures is a very serious objection to the use of battery ignition in cold climates especially in these times when the poor old battery is asked to do so many things. This is one of the considerations that has led the Department to turn down the booster coil in favor of the hand starting magneto. The aircraft and its crew must be self-supporting and in the final analysis the energy for starting may have to be derived from the calories in the emergency rations supplied for the men. This is not far fetched. Many a pilot in the North has taken the spark plugs to bed with him in the eiderdown bag so as to be sure that they would be warm and dry when required for use the next morning. Incidentally it is quite common technique to warm at least one plug out of each cylinder on a shovel over the engine warming stove. This is not so convenient when a simple engine cover is being used.

To insure lubrication at the start, Professor Robb tried both "Mobil A" and "Mobil Arctic" and decided definitely in favor of the latter. A little "Arctic" was left in the crankcase overnight and the tank was short circuited by means of a bypass with a relief valve leading to the tank so as to control the pressure on the suction side of the oil distributing pump. This idea is similar to that of the segregation of a portion of the oil tank but it has the disadvantage that some one might forget to cut in the main tank.

Experiments were also made at this time with jets of various sizes larger and smaller than the standard high-speed jet. As might be expected, because cold air has more oxygen per unit volume than warm air, the standard jet was inclined to give a lean mixture and the engine was found to take the throttle better with a slightly oversize jet (070 as against 065 on the Liberty).

The danger of vapor lock at high altitude or at high temperature definitely precludes aviation gasoline from being a really easy starter, at least in the present stage of the art. To achieve the ideal of dead cold starts, therefore, it will be necessary to resort to a starting fuel such as ether or some gaseous fuel compressed into a bottle and injected into the intake manifolds. It must be confessed that the lead given by Professor Robb has been somewhat neglected for a long time, but some of the blame can be attributed to the engine manufacturers who were, to say the least, reluctant to tolerate the use of low viscosity oils. So long as the necessity for warming the oil and the motor was accepted, so long was the methodical development of easy starting retarded.

Valve and Accessory Lubrication

There is a fairly strongly supported opinion that much of the difficulty of getting the first kick can be attributed to poor compression caused by sticky valves. This immediately brings up the question of valve lubrication and it is a fact in Canadian experience that liquid-cooled engines start more easily than the air-cooled type. In the effort to get a clean engine which does not foul the windscreen, there is a suspicion that we in Canada, at least, have gone a step too far in packing the valve rocker boxes with over heavy grease. The winter grease is, of course, lighter than that used in summer, but even at that it is probably unnecessarily viscous. The introduction by Pratt & Whitney of pressure lubrication to the valve gear will probably prove to be of definite advantage in cold weather operation, though the drainage of the oil from the lower cylinders through the exposed manifold of apparently rather small dimensions may be attended by some trouble unless low-viscosity low-pour-point oil is used. It is, however, encouraging to relate that in a certain engine with which we had to deal a low pressure lubricating pipe leading forward outside the crankcase to the reduction gear case was looked upon with considerable suspicion and a special pressure gage was fitted to supervise it and yet no untoward events happened.

It may be taken as axiomatic from the point of view of the cold weather operator that all lubrication of the motor and its accessories should depend on one single supply of oil under pressure with the possible exception of the starter which begins to turn before the pressure pump gets going. So far as the author knows the problem of cold weather lubrication of packed bearings, such as are installed in electrical machinery, has not been tackled seriously and probably needs some attention. It does not appear to be vital.

The inertia starter is the most commonly used kind in Canada and it is absolutely essential to prepare it for winter use by cleaning it thoroughly and repacking with a low viscosity lubricant. This applies whether the starter is electrically energized or wound up by hand.

Icing of Carburetor

One of the worst bugbears of cold weather flying is the danger of icing up in the choke of the carburetor. Many carburetors are furnished with a special heating jacket round the choke housing to forestall this evil. In Canada we probably suffer less from this than most countries in the Northern Temperate zone, because, with the possible exception of the coastal regions, the relative humidity of the atmosphere is comparatively low for the greater part of the winter. Trouble is definitely experienced in the fall and spring. The accepted method for combating the evil is to reduce the relative humidity of the intake air by warming it. The cheapest way is to use the air that has just finished cooling a nice hot cylinder or two, but if this device entails an air intake inside the cowling it is wise to fit a flame trap as an ordinary precaution against fire. The air intake positively must drain to the outside of the cowling. Heat from exhaust gases is frequently employed to warm the incoming air, but this involves extra complication and expense in the exhaust system and especially careful inspection and maintenance to insure that the engine will not be fed through leakages with some of its own exhaust.

Future Ambitions

Although much of this paper is devoted to describing methods for warming motors and oil tanks, emphasis should be placed on the efforts to eliminate all this unproductive labor. Our proposals for engine warming and oil heating are merely made with a view to finding good expedients to carry through until the ideal is reached. So far, as implied before, the stage has been reached where a 63 sec. special low pour oil can be used dead cold for a start at —20 deg. fahr. Unfortunately not all motors will start at this temperature and the immediate problem is to get the technique for cold motor starting into

line with the progress on lubrication. When that has been achieved it is proposed to aim at a figure of some —40 deg. fahr. It nearly all depends on the wonderful efforts of the petroleum technologists who are certainly learning to weave their molecules into newer and more pleasing patterns every day. A lot of people will consider that 63 sec. oil is beyond the pale of reason already but there is little cause to doubt that there will soon be available a 53 sec. oil with a remarkably good viscosity index and in the meanwhile we can make sure of the ground where we stand. The ultimate aim to be achieved is dead cold starts at temperatures just above the freezing point of gasoline, namely, around —70 deg. fahr., which is about the limit of human endurance. Before we ever reach this point, however, there is quite a possibility that the internal combustion motor will be displaced by a steam powerplant, which has many attractive possibilities for winter operation, and that gasoline as a fuel may give way to something else altogether.

Appendix I

Some results of tests of low viscosity oils used in a Wright R975E Engine installed in a Bellanca Pacemaker.

Oils Used

Imperial Marvelube.....A3
Imperial Marvelube.....A2 (1928)
Imperial Marvelube.....A2 Special (63 sec.)

Average Oil Consumptions

A3.....2.4 pt. per hr. (16 hr.)
A2 (1928).....2.4 pt. per hr. (60 hr.)
A2 Special.....3.16 pt. per hr. (115 hr.)

Note:—Average r.p.m. were somewhat higher when using the A2 Special than with the other oils.

Maximum Oil Consumption Recorded

A2 Special.....4.1 pt. per hr.

Range of Cylinder Head Temperatures Cruising 1700—1800 r.p.m.

No. 1 cylinder..... 350 - 450 deg. fahr.
No. 4 cylinder..... 300 - 400 deg. fahr.
No. 7 cylinder..... 300 - 400 deg. fahr.

Oil Temperatures Maintained

Grade	Maximum	Average
Marvelube A3.....	56 deg. cent.	52 deg. cent.
Marvelube A2 (1928).....	53 deg. cent.	45 deg. cent.
Marvelube A2 Special....	54 deg. cent.	45 deg. cent.

AIRCRAFT V. C.—ENGINE C. W. 155. Oil Marvelube A-2 Special A. 303/32 Date—March 17, 1933

Time		Oil Temperatures Deg. Cent.			Oil Pressure		Cylinder Head Temperature Deg. Fahr.									
Hr.	Min.	Into Cooler	Out of Cooler	Into Engine	Engine	Cooler	No. 1	No. 4	No. 7	Mixture Control 1-Full Open	Cooler and Engine Shutter 1-Full Open C	E	Altitude Ft.	Air Speed Indicator M.P.H.	Air Temperature Deg. Cent.	R.P.M.
..	00	22	16	14	..	..	...	...	...	..	..	..	Ground	..	....	....
..	01	21	15	12	50	12	...	...	...	1	0	0	Ground	..	....	760
..	02	20	15	12	53	11	...	...	...	1	0	0	Ground	..	....	800
..	03	19	15	12	52	10	...	...	...	1	0	0	Ground	..	....	790
..	04	20	16	13	51	11	...	...	...	1	0	0	Ground	..	....	800
..	05	20	16	14	52	11	250	210	240	1	0	0	Ground	..	....	810
..	10	23	20	17	50	10	270	240	270	1	0	0	Ground	..	....	820
..	15	29	25	23	60	10	430	380	410	1	1	0	1200	79	–3	1840
..	20	39	34	25	58	8	420	380	410	1	1	0	3900	74	–9	1820
..	25	46	40	32	59	8	380	330	360	½	1	0	4200	87	–11	1750
..	30	48	40	36	59	8	390	320	360	½	1	1	4350	91	–10	1760
..	35	47	40	36	59	9	400	320	360	½	1	1	4350	90	–9	1760
..	40	47	39	36	60	9	400	320	360	½	1	1	4500	90	–9	1770
1	00	46	39	33	60	9	400	330	350	½	1	1	4500	92	–8	1780
1	30	Landed at St. Hubert. No Readings taken														
2	00	45	40	33	59	10	400	320	360	½	1	0	6100	86	–12.5	1750
2	30	45	38	32	60	10	380	310	340	½	1	0	6800	85	–13.5	1780
3	00	44	37	30	60	10	380	300	340	½	1	0	6500	93	–14.5	1780
3	30	43	35	30	60	10	370	300	340	½	1	0	6800	89	–16	1780
4	00	44	37	31	60	10	360	330	330	½	1	0	6300	90	–15	1750
4	30	42	37	29	59	10	370	300	340	½	½	0	6700	85	–14	1780

A. S. I. No. 23571—Altimeter No. 2496—All-up Weight 4300 lb.

Ground Temperature....1.0 deg. cent.
Wind.....N. W. 20 M.P.H.
Altimeter Reading Feet.
Surface..Sticky Snow 6–8 Inches Deep
Take-off Time.....32 Sec.

Oil Data

Temperature in tank after filling.....15 deg. cent.

	Gross	Net
Weight in.....	50.0	..
Weight out.....	31.0	..
Consumption.....	19.0	..
	3.5 lb./hr.	

Fuel Data

Gallons in after flight.....70
Consumption.....13.7 gal./hr.

Time—Engine and Flying

Engine on.....	1250 hr.
Off.....	1815 hr.
Engine time.....	5 hr. 25 min.
Take-off.....	1300 hr.
Land.....	1815 hr.
Flying time.....	5 hr. 5 min.

Starting—Engine
NO DIFFICULTY
Skis—Remarks—E Type.
Performance good considering surface conditions.

Time		Oil Temperatures Deg. Cent.			Oil Pressure Lb. Per Sq. In.		Cylinder Head Temperature Deg. Cent.			Air Speed Indicator	Air Temperature		
Min.	Sec.	Into Cooler	Out Cooler	Into Engine	Engine	Cooler	No. 1	No. 4	No. 7	M. P. H.	Altitude Ft.	Deg. Cent.	R. P. M.
Ground		24	24	18	62	11	380	320	360	..	....	−2	1740
1	35	34	30	24	60	9	420	380	400	85	1000	−4	1840
2	55	36	32	27	60	9	420	380	400	83	2000	−7	1860
4	35	40	35	29	59	9	420	380	400	77	3000	−7.5	1820
6	20	42	37	30	58	8	440	390	400	75	4000	−8	1820
8	20	45	39	30	58	8	440	380	400	73	5000	−8	1830
10	15	48	41	31	58	7	430	380	400	74	6000	−8	1840
12	45	50	43	32	57	7	420	370	400	75	7000	−7	1850
15	30	52	44	34	57	7	410	360	390	74	8000	−5.5	1860
17	45	53	45	35	56	7	400	360	380	73	9000	−6.5	1860
21	00	54	44	34	57	7	400	360	380	72	10000	−8	1860

Note: Oil temperature dropped to 48 deg. cent. in 15 min. cruising 1750 r.p.m., Air Speed Indicator, 76 m.p.h. at 10,000 ft. Cooler and engine shutters open.
Head temperatures after 15 min. cruising—No. 1 400, No. 4 340, No. 7 360

Full throttle climb to 10,000 ft., ground temp. —2 deg. Cent. Marvelube A-2 Special Oil. Date, March 13, 1933. Engine and cooler shutters open. Mixture control adjusted for best running. Aircraft on skis

Appendix II

Technical Memorandum No. 104
Issued by
Aeronautical Engineering Division
Department of National Defence

Lubrication of Aero Engines

1. The wide range of climatic conditions which are encountered in different parts of the Dominion of Canada has necessitated extensive experimental work by the Department of National Defence with the object of developing a general technique to meet the requirement of aero engine operation under extreme temperature conditions, with particular reference to extreme cold.

2. For the purposes of this memorandum it will be assumed that the chemical properties of lubricants are not under discussion and that the physical properties including the elusive property best described as "oiliness" are acceptable. The physical characteristic known as Viscosity then stands out as having a ruling influence on lubrication.

3. In explanation of Viscosity the following quotation from Glazebrook's Dictionary of Applied Physics will serve admirably:

> "When relative motion exists between neighbouring portions of the same fluid, a measurable resistance to the relative motion can be observed and affords a proof that actual fluids are capable of sustaining shearing stresses; the fluid is said to exhibit the property of viscosity or internal friction."

The relation between the shearing stress in a fluid and the rate of distortion (or flow) of the fluid is known as the COEFFICIENT of Viscosity and it is useful to regard this coefficient as a STATE rather than as a property or characteristic because it varies with temperature. It is then easy to understand that a lubricant must not only possess the right properties, but must be in the right state in order to perform its functions satisfactorily.

4. In any given aero engine the oil feed pump and relief valve are designed to work within fairly well defined limits, that is to say the applied shearing stress which creates the flow of lubricant is approximately fixed and consequently for a given range of flow the coefficient of viscosity must also remain within fixed limits. If the coefficient of viscosity is too high the flow will be too small and though the oil film in the plain bearings may be strong enough to take the bearing pressure there will not be enough oil spilt to lubricate the cylinders and pistons. Conversely if the coefficient of viscosity is too low there will be too much spillage and the plain bearings will be starved. Departure from the range of viscosity accepted in general practice would necessitate alteration of the oil feed pump and of the clearances in the engine.

5. As correct lubrication depends on rate of flow at a given pressure and as the rate of flow depends upon the coefficient of viscosity which in turn depends on temperature it will be clear that the oil pressure gauge and temperature gauge provide approximate but quite adequate means of supervision of the STATE of the lubricant in the engine.

6. Nearly all engine manufacturers issue recommendations concerning the grade of oil and the corresponding temperature and pressure found by experience to be suitable for their engines. It must be borne in mind that a statement of recommended oil temperature means nothing at all if it is not accompanied by a complementary statement of the grade of oil, but if the whole information is given the correct STATE of the lubricant in the working engine can be inferred, and the inference may be used with intelligence and discretion in the deliberate variation of temperature with grade to meet different atmospheric conditions.

7. The accompanying chart A.S.S. 138 shows the relationship between Saybolt viscosity and temperature for a number of well known oils. A Centigrade scale is given at the top and a Fahrenheit scale at the bottom. Study of the chart will show that the permissible range of viscosity is wide, and that the oil for curve "A" will have the same state of viscosity at 120°F as the oil for curve "H" at 172°F. Actually it will be found that most aero engines work very near the lower boundary of the operating zone, and it is quite possible, and even probable, that this boundary will be lowered, but the Department has no experience so far to justify such action immediately. The modern automobile works much lower down, but seldom works continuously at high throttle openings. The chart has been prepared for oil inlet temperatures, and the preferred position for the oil temperature gauge is in the inlet line, as this gives a more direct indication of the state of the oil entering the lubrication system. A rough assumption has been made that the outgoing oil is 20°F hotter than the ingoing oil, but this may not be even nearly correct in some installations, and it is strongly recommended that owners should check this for themselves if their aircraft happen to be fitted with a temperature gauge on the outgoing oil line only.

8. During periods of abnormally high atmospheric temperature the cooling of the whole oil system will be reduced and the temperature of the oil stream increased. The drop in viscosity corresponding to the increased temperature increases the flow through the engine with a further increase in the temperature of the oil stream. Provided that a stable condition of oil temperature and viscosity within the limits of the chart is obtained without appreciable loss of oil pressure the engine may be operated safely though an increase of oil consumption is to be expected. Recourse may be had to an oil of higher viscosity if 120 sec. oil Ref. No. 34A/15 is not already in use. It is not considered desirable to use oil of viscosity greater than 120-125 secs. as any advantage gained during full throttle operation or when climbing will be more than offset by a sudden change from the abnormal atmospheric conditions, and during warming up. Failure to obtain stable conditions of temperature, within the limiting temperature range, in the oil stream even in abnormal high atmospheric temperatures may be taken as an indication of defect in the installation and should be reported as such.

9. Extensive warming up periods, during cold weather may be accompanied by excessive wear of cylinder walls and pistons with a certain amount of "scuffing" of the surfaces which will result in further wear when the engine is placed on load and reduction in the life of the engine to a greater extent than occurs during summer flying operations. Several methods, which may be used separately or together, are available for preventing this trouble; viz:

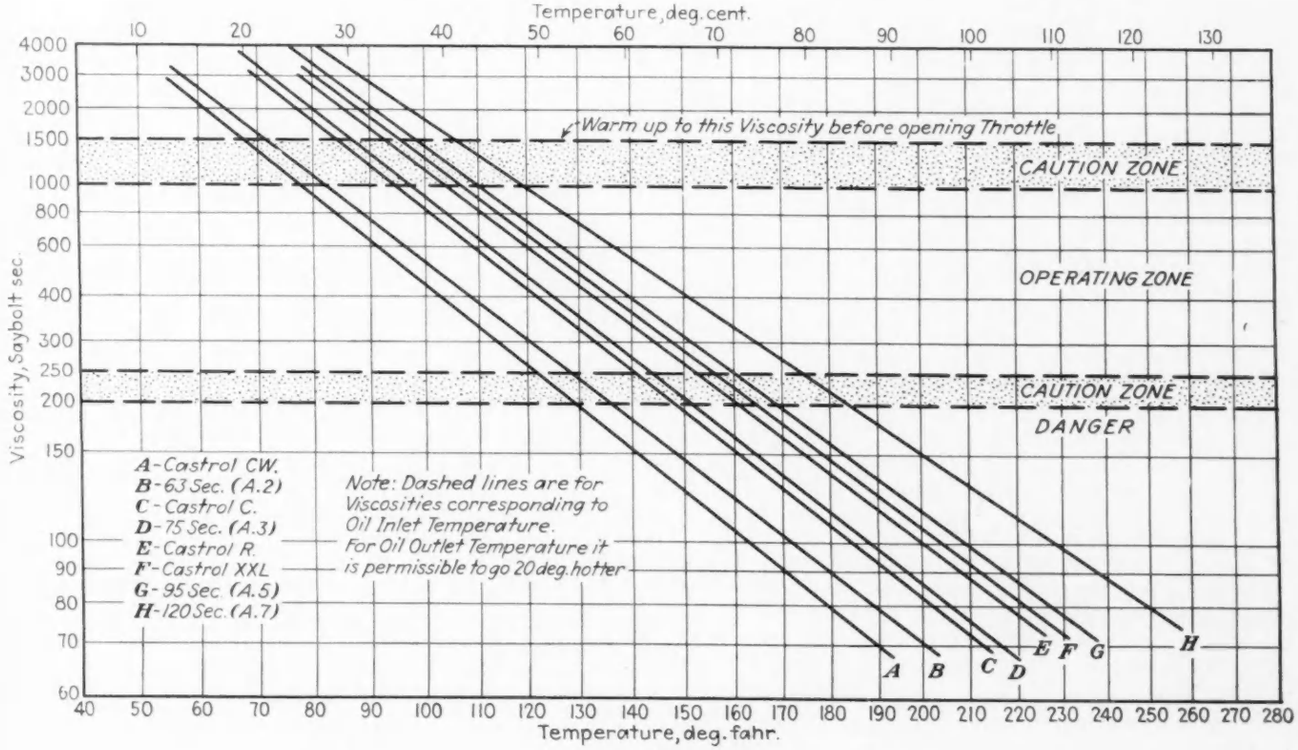
(a) Change of oil to a lighter grade, when the normal cooling effect of the system is such that the desired viscosity of the oil going into the engine can be maintained.

(b) Similar to (a) but to a lesser degree by addition of oil of a lower viscosity, to that already in the system. This method should be confined to oils of the same brand as it is not desirable that castor or castor compounded oils be added to mineral oils.

(c) On training aircraft operated in the vicinity of an aerodrome the minimum quantity of oil permitted by the engine manufacturer plus the amount of the estimated consumption for a convenient period of flight may be used to provide a more rapid flow with correspondingly shorter time required for warming up.

(d) Preheating the oil.

10. Outside the engine a good lubrication system should include an oil tank, or tanks well protected from the warm air


Temperature, deg. cent.
10 20 30 40 50 60 70 80 90 100 110 120 130
Viscosity, Saybolt sec.
4000 3000 2000 1500 1000 800 600 400 300 250 200 150 100 90 80 70 60
Warm up to this Viscosity before opening Throttle
CAUTION ZONE
OPERATING ZONE
CAUTION ZONE
DANGER
A-Castrol CW.
B-63 Sec. (A.2)
C-Castrol C.
D-75 Sec. (A.3)
E-Castrol R.
F-Castrol XXL
G-95 Sec. (A.5)
H-120 Sec. (A.7)
Note: Dashed lines are for Viscosities corresponding to Oil Inlet Temperature. For Oil Outlet Temperature it is permissible to go 20 deg. hotter
A B C D E F G H
40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280
Temperature, deg. fahr.

See Appendix II

from the engine and from the cold atmosphere, and a controllable oil cooler in the scavenge line. The cooler should be of such a capacity as to keep the oil temperature under the pilot's control over a considerable range of atmospheric temperature. In this way two or three grades of oil may be made to do for the entire climatic variation in Canada throughout the year. On aircraft not fitted with oil coolers it will probably be necessary to use a greater number of grades of oil. On wet sump engines the variation of grade from that recommended by the manufacturer must be done with great caution, for though it is most desirable in cold weather to use a low viscosity oil for starting, it must be remembered that when running, the wet sump engine is not affected by outside conditions to the same extent as a dry sump engine, and the upper temperature limit of the oil is not controllable.

11. The Department's experience with aircraft having common types of radial air cooled engines up to 425 H.P. and controllable oil coolers is that 63 sec. oil (curve "B" on the chart) remains fluid at 20°F below zero, and can be safely used up to an atmospheric temperature of 32°F, and that the 95 sec. oil (curve "G") is satisfactory for the upper range of atmospheric temperatures, except for really abnormal hot weather. In radial engines without oil coolers it is thought to be advisable to change to 75 sec. oil (curve "D") for the atmospheric range 0°F to 32°F. For temperatures below −20°F 63 sec. oil should be warmed before starting up, but as it is probably necessary to warm the engine anyway to get a start, the one source of heat may be enough to heat the oil in the tanks as well as to heat the engine.

12. The primary reason for oil changing is to remove the solid matter which accumulates in the oil system. A portion of this material will settle out while the remainder is held in suspension. It is doubtful if the particles which are fine enough to be held in suspension are sufficiently large to cause damage to the bearing surfaces, but the sediment is agitated by circulation of the oil and may contain particles of considerable size though sufficiently small to pass the oil strainer screen. The most serious result of this sediment is its precipitation in the crank pins by centrifugal action and the possible sealing of the oil channels to the connecting rod big end bearings which also cuts off the supply to the cylinders and pistons. Oil changing, when necessary, should take place immediately after the engine has been run, to minimize the quantity of sediment remaining in the system. Twenty (+−5) hours flying is a safe period between oil changes for present engine installations, based on normal operation. It is reasonable to use a shorter period when conditions of operation have been abnormal, that is, long periods of full power, overheating, etc., and on training aircraft operated from sandy or dusty aerodromes.

E. W. Stedman,
Chief Aeronautical Engineer.

Addendum

1. With reference to paragraphs 6, 9, 10, and 11, of this Memorandum, it is desired to emphasize that they are in no way intended to prompt any departure which would not meet with the full approval of the engine manufacturers. Operators are, on the contrary, advised to maintain the closest touch with the manufacturers of their engines concerning the problems under discussion, and they should understand clearly that the full benefit of the use of lighter grades of oil cannot be achieved without the use of an adequate controllable oil cooler.

Appendix III

Weights of an Existing Engine Warming Equipment

Engine cover	28 lb.
Chimney and thermometer	19
Chimney base and primus stove	8
Lighting stand	5
Flexible piping	3
Auxiliary primus burner	4
Gasoline container (pressure vessel)	18* (empty)
Methylated spirit	1
Oil container	17*
	103 lb.

* Capable of reduction by redesign.

Flame Temperature Variations

(Continued from page 136)

up this internal energy despite the large number of collisions and despite the almost instantaneous change in temperature of these products of combustion. This assumption is essentially the hypothesis advanced some time ago by David, and Dr. Lewis has already treated this subject in his discussion.

Near the spark plug, Marvin, Caldwell and Steele observed that the radiation, which according to their experiments was emitted chiefly by CO_2 and H_2O molecules, increased after the appearance of the flame until maximum pressure was reached. Such an increase in radiation can only be used as valid evidence for afterburning if no other cause for the increased radiation can be found. But, it has now been shown that, in addition to the rise in density of the inflamed charge resulting in an increased number of radiating CO_2 and H_2O molecules beneath a window, the temperature of these gases near the spark plug increases after inflammation until maximum pressure is attained. There seems to be no doubt that raising the temperature of such gaseous molecules under engine conditions will increase the rate at which they radiate energy. Therefore, to attribute any part of the increased radiation to afterburning is mere speculation unless it is first shown either (*a*), from independent evidence, that afterburning does take place and does increase the radiation, or (*b*) that the effects of the increasing temperature and density are not sufficient to account for the increased radiation.

Regarding the observations at the opposite end of the combustion chamber, we see no way of deciding what effect the window recesses are having except by experiment; but in support of our stand that burning in these recesses may have influenced the radiation measurements presented by Marvin, Caldwell and Steele, rather than afterburning within the combustion space proper as they have inferred, the work of Hershey[50] is cited. He measured total radiation—including the infrared up to the limit of transmission of quartz—through a flush-mounted window, so located that his measurements include radiation from both the first and last parts of the charge to burn. Maximum radiation was observed at or very close to the time of maximum pressure, which observation is distinctly different from the results presented by Marvin, Caldwell and Steele. Under non-knocking conditions the data obtained by these workers through a pocketed window above the part of the charge which burned last, showed maximum radiation 20 deg. after maximum pressure.

[50] See *Industrial and Engineering Chemistry*, 1932, vol. 24, p. 867; Hershey.

The Lubrication Requirements of Automotive Worm Gearing

By C. H. Schlesman
Socony-Vacuum Oil Co.

THE characteristics of automotive worm gearing have been investigated through the use of a special dynamometer installation capable of testing standard passenger-car and bus axles. The equipment employed in the measurement of the efficiency and of maximum permissible torque attainable with various lubricants has been described.

A complete study of the effect of lubricants upon gear performance requires measurement of the rate of wheel-tooth wear, the amount and nature of corrosion, and the extent of lubricant oxidation and polymerization, as well as investigation of the rate of wheel pitting. Researches carried out for the purpose of studying the mechanism of tooth fatigue are described, and the results of the study reported.

The conclusion is reached that no single lubricant possesses all of the characteristics desired in worm-gear lubrication. It has been found that the product which proves to be the most suitable for one class of service has serious objections when employed under other conditions of operation. The suggestion is made that information relative to lubricant characteristics and the conditions of service to which they are to be subjected be secured before final selection of lubricant is made.

THE automotive laboratories of the Socony-Vacuum Oil Co., Inc., were recently assigned the task of explaining the short life sometimes experienced with worm axles in typical fleet service. This involved study of (*a*) the nature of the power losses occurring in worm gearing; (*b*) the causes of solidification of axle lubricants under severe conditions of service; (*c*) the reasons for excessive failures of wheels through pitting; and (*d*) the nature of corrosion and wear of tooth surfaces.

[This paper was presented at the Annual Meeting of the Society, Detroit, Jan. 18, 1935.]

In attacking this problem, the use of full-scale axles was considered imperative; also, that all tests be carried out with commercially produced automotive worm gears which had been cut on standard production equipment. For this reason, in initiating the investigation, bus, truck, and passenger-car worm-gears were purchased and a complete axle-dynamometer installation was developed.

While small industrial worms and wheels have been employed successfully in such investigations by others, the great differences in the composition and hardness of the bronzes, and the large errors in the pitch of the worm, together with poor alignment of the gears under load, made this form worthless for the purposes intended.

To summarize the results of our work briefly, we conclude that no single product possesses all the desirable characteristics of a worm-gear lubricant, but that the best lubricant must be selected for each class of service.

Lubricants which are composed entirely of vegetable or animal oils can, under certain conditions, show smaller power losses in an axle than are possible with mineral oils, and permit operation at the heavier loads without tearing or scuffing of the tooth surfaces; however, these vegetable oils oxidize more rapidly, and cause higher rates of gear wear than do the best mineral oils.

Under other conditions of service, the use of specially thickened oils, or greases, is necessary. These products, while less stable than mineral oils, are particularly useful in preventing leakage. Greases, in general, however, suffer from the disadvantage of causing bronze chips, always present with the lubricant, to float into the anti-friction bearings.

The use of extreme-pressure lubricants with worm gears, although generally undesirable, may be a remedy for overloading of the anti-friction bearings. Very active extreme-pressure lubricants, however, produce rapid wearing away of the wheel. This class of lubricant is also prone to cause corrosion of the worm and worm bearings. Thus, with conventional worm gears, it has been concluded that a well-refined oil is the most satisfactory lubricant for general use, where tooth loadings are not excessive. Such products provide adequate lubrication and combine the ability to hold wheel wear to a very low point, with remarkable resistance to oxidation and freedom from corrosion troubles.

Where worm gears are employed in tractor-trailer installations, particularly in the mountains on the Pacific Coast where the load-carrying ability of the lubricant is of paramount importance, a compounded lubricant containing a blend of animal or vegetable oils and synthetic petroleum fatty

acids is to be preferred. Lubricants of this type will prevent tooth scuffing at loads far beyond those which can be permitted from a fatigue standpoint.

Highly stable soap-thickened oils are sometimes specified for use in lubricating fleet equipment, where the maintenance of wheel bearings and worm seals is a problem. These products may have sufficient resistance to oxidation to provide a reasonable service life; however, they are inferior in this respect to mineral oils, and are subject to difficulties as a result of contamination with water and other service conditions. Thus it follows that, in developing lubricants for automotive-worm applications, their suitability must be considered from seven viewpoints.

(1) Losses produced by churning of the lubricant
(2) Efficiency of the gearing at normal loads
(3) Ability to carry maximum loads without seizure
(4) Effect of lubricant upon fatigue limit
(5) Stability in service
(6) Effect upon rate of wheel, worm, and bearing wear
(7) Effect upon surface finish of worm, wheel, and bearings

The performances obtained from various types of lubricant are given in Table 1, which compares the performance of a number of products, during consecutive 9200-mile dynamometer-runs, each run being made with a new wheel and worm assembly. Examination of Table 1 will illustrate the nature of the compromises which must be effected in designing worm-gear lubricants.

Using the values given in Table 1, one would select the vegetable oil, Lubricant *D*, as the best, from the standpoint of efficiency; however, its use would be objected to in severe service, as a result of its low resistance to oxidation and the formation of free fatty acids which accelerate tooth wear. This same lubricant, *D*, appears to be of considerable interest for use in applications where the formation of tooth pits is causing premature discarding of wheels.

Lubricant *A*, a well-refined mineral-oil, on the other hand, appears to possess all the qualities which product *D* lacks. This oil shows low tooth wear and a surprizingly high resistance to oxidation, and is free from the troubles caused by foaming and the flotation of bronze chips, yet such a product cannot be employed where the tooth loads are exceedingly high.

The exceedingly high rate of wheel-tooth wear occasioned by the use of Lubricant *B*, a vigorous extreme-pressure lubricant, is very evident. It is interesting to note that this lubricant lost film strength rapidly during service, falling from 15,000 + lb. per sq. in., Almen, to 6000 lb. per sq. in. in 9200 miles of service.

Lubricant *C*, a specially compounded oil, and Lubricant *X*, a grease, show no outstanding characteristics; however, their use is desirable under certain conditions of operation.

A better picture of the value of each of these lubricants may be obtained by referring to Fig. 1, in which the height of the shaded portion indicates the merit of the lubricant Here, the relative merit of each of the lubricants has been weighted, under the seven groupings previously referred to.

The use of Fig. 1 would lead to the selection of Lubricant *D* as the product showing the highest efficiency in service. It is also capable of sustaining the highest torque. If minimum wear of the bearings and of the wheel teeth were considered of paramount importance, Lubricant *C* would be selected as most suitable. Mineral Oil *A* or Lubricant *C* would be selected for severe service, where rapid oxidation of the oil might cause service difficulties.

Since the factors discussed are not of equal importance in determining the value of gear lubricants, some form of

Table 1—Comparing Service Changes Occurring in Worm Axle and Lubricants During Consecutive 9150-Mile Dynamometer Tests at a Sustained Speed of 65 M.P.H. and an Oil Temperature of 230 Deg. Fahr.

	Mineral Oil	Extreme-Pressure Lubricant	Specially Compounded Oil	Vegetable Oil	Grease
Lubricant	*A*	*B*	*C*	*D*	*X*
(1) Churning Losses at 65 M.P.H., in Horsepower.	2.35	2.50	2.28	1.73	....
	Average Efficiency between 4500 and 9150-Mile Point (Sustained Load, 60 Hp.; Oil Temperature, 230 Deg. Fahr.)				
(2) Efficiency at Normal Load, Per Cent	89.09	90.39	89.08	90.66	88.33
(3) Maximum Permissible Loading at 2100 R.P.M. in Lb-Ft.	187	216	188	225	181
(4) Extent of Wheel Fatigue	Area of Pits on Wheel Teeth; 9150 Miles				
Square Millimeters	6.15	4.04	11.24	0.88	8.00
Square Inches	0.00953	0.00626	0.0237	0.00136	0.0128
(5) Stability in Service (*a*)	Viscosity Changes, Sec.				
New Oil (S.U.V.) 210 Deg. Fahr.	152	160	146	96	A.S.T.M. Cone Penetration, 350 mm.
Oil after 9150-Mile Service	166	171	160	118	
(*b*)	Oxy Material Formed in 9150 Miles of Service				
Oxy-Material by Weight, Per Cent	0.063	3.120	0.003	0.179	
Loss of Film Strength (*c*)	Film Strength, Lb. per Sq. In.; Almen Machine				
New Oil	6,000	15,000+	7,000	7,000	
Oil after 9150-Mile Service	5,000	6,000	5,000	6,000	
(6) Rate of Wheel and Bearing Wear	Wheel-Tooth Wear, In.				
	0.00258	0.01635	0.00153	0.00969	0.00436
	Average Bearing Wear, In.				
	0.0070	0.00612	0.0021	0.0035	0.0043
(7) Effect upon Surface Finish (*a*)	Polish Imparted to Wheel-Tooth Surfaces				
	Matt Surfaces	Satin Finish (Wheel badly discolored)	Polished	High Polish	Matt Surface
(*b*)	Corrosion of Worm and Bearing Surfaces				
	None	Excessive	Slight	Insignificant	Slight

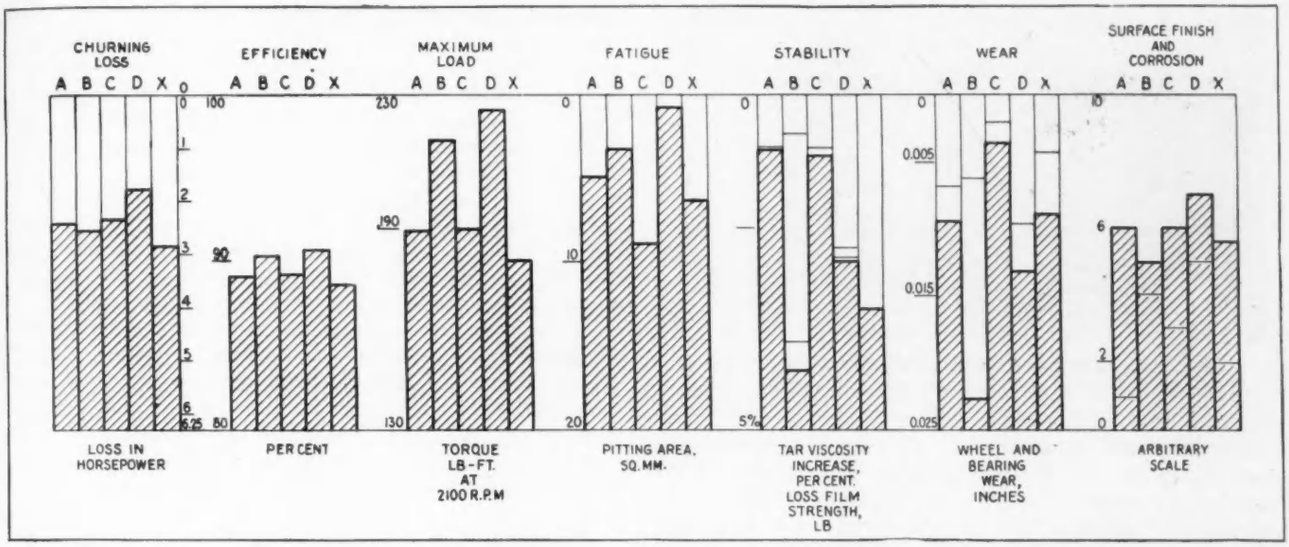


Fig. 1—Chart Showing the Value of Each of Several Lubricants

weighting must be resorted to in order to determine which product most nearly meets the requirements of a given set of service conditions. In Table 2, each factor has been weighted in accordance with its importance under average fleet conditions of operation. The system of weighting employed assigns the greatest importance to stability under service conditions of operation. Passenger-car designers and bus operators will agree that lack of stability is probably responsible for more field difficulties than any other single factor. Where resistance to oxidation and thickening is important, products such as Oil *A* or Lubricant *C* must be chosen.

Where special service conditions exist, other weights must be given to the various groups. For example, Lubricant *D* would receive the highest number of points, if the suitability of the products for use at high tooth loading was considered, above all other characteristics.

In arriving at these conclusions, the effects of various lubricants upon the performance of worm gears were considered. If the properties of the lubricants themselves are studied, other important characteristics are disclosed.

Worm-Gear Lubricants

In general, materials employed in the lubrication of worm gears may be considered as falling into the following classes: Mineral oils, compounded oils, extreme-pressure lubricants, and greases.

Mineral oils are perhaps the most popular lubricants for use with bronze wheels running against steel worms. In severe service, where tooth loadings are not too high, oils of this type are extremely satisfactory; however, since mineral oils differ widely in their chemical characteristics, they must be selected with care. Oils to be suitable for this purpose must possess the following characteristics: Low channeling point, high resistance to oxidation, reasonably flat viscosity-temperature curve, and proper viscosity at operating temperatures.

It has been demonstrated that the A.S.T.M. pour-point is not a suitable index of the channeling tendency of oils. The only satisfactory test for channeling appears to involve the running of the axle in the cold room with the lubricant under test.

The most reliable test for oxidation resistance is a simulated service test carried out with the axle dynamometer. In this test, the oil to be studied is employed in the lubrication of a worm-geared axle during the equivalent of 10,000 miles of service. A sustained load of 50 to 65 hp. at a temperature of 230 deg. fahr. has been found to be desirable. Under the conditions set up in the test axle, thickening and oxidation of the lubricant can readily be observed and measured.

Oils having viscosities between 160 and 200-sec. Saybolt at 210 deg. fahr. should not cause trouble as a result of leakage; however, we have encountered axles in the field which cannot be lubricated with products of this viscosity, because of excessive leakage. Such leakage in the field must even-

Table 2—Comparing the Weighted Service Value of Lubricants. Weights Assigned in Accordance With the Importance of the Various Properties in Average Fleet Operation

Lubricant	Churning Loss	Efficiency	Maximum Load	Fatigue	Stability	Wear	Surface Finish of Corrosion	Total	Per Cent
Weight	20	50	30	20	100	30	20	270	100
A	12.2	23.2	17.8	15.1	83.2	18.5	12.0	182.0	67
B	12.3	26.0	25.9	18.2	17.2	2.6	10.0	112.2	41
C	12.9	23.3	18.0	12.5	81.6	25.6	12.1	186.0	68
D	14.1	27.0	28.6	20.7	49.6	14.0	14.0	168.0	62
X	11.0[a]	25.6	15.1	15.1	35.0[b]	19.2	11.3	132.3	49

[a] Estimated.
[b] Based upon all types of service change. Includes changes produced by moisture.

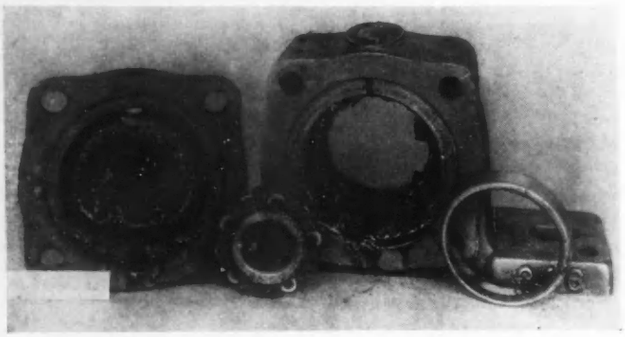


Fig. 2—Anti-Friction Bearing Failure Occasioned by Oxidation of a Compounded Lubricant

tually be cleared up by the use of better seals or by better axle design. Certainly, few things are as humorous as the attempts of some of our leading automotive engineers to staunch the flow of oil onto the brake drums after their latest creation has appeared in service.

Straight mineral oils are not suitable for use with worm gears which operate at exceedingly high tooth pressures. At such loads, scuffing or tearing of the tooth surfaces occurs, and overheating results. This condition may frequently be corrected by the use of compounded oils having high oiliness coefficients.

Compounded Lubricants

In general, compounded oils show poorer resistance to oxidation than do mineral oils. The experience of truck owners, who have discovered that certain axle lubricants turn to a rubber-like mass in service, may be traced to the use of unstable fixed oils. The rate of oxidation and of thickening of a variety of lubricants was compared in Table 1. It will be remembered that one of the most stable products was the highly refined petroleum oil, Sample *A*. This oil was virtually unchanged after 10,000 miles of operation. Sample *B*, a compounded extreme-pressure lubricant, showed important changes. Lubricant *D* showed slight oxidation and thickening. This same product has been completely destroyed in other slightly more severe test runs.

Fig. 2 illustrates the appearance of an anti-friction bearing operated under standard test conditions. It will be noted that this lubricant, *D*, castor oil, was severely oxidized during this test. This is accounted for by the rapidity with which it forms rubber-like polymerization products. During this test, destruction of the bearing separators occurred, and roller failures resulted.

Equally disastrous results may occur in service whenever poorly compounded oils are employed. For example, the presence of an excessive amount of free fatty acids will frequently cause the corrosion of steel parts. The amount and nature of free acids present must be particularly well controlled when anti-friction bearings are used.

In some classes of service, compounded lubricants which were apparently satisfactory when new failed in operation as the result of the separation of the compound from the mineral oil. Such separation can almost always be traced to oxidation or to improper compounding practice.

Extreme-Pressure Lubricants

The popularity of extreme-pressure lubricants has led to the widespread use of this class of material for the lubrication of worm gears. In general, such use is unsatisfactory, since the characteristics required of extreme-pressure lubricants are entirely different from those desired in worm-gear work. While the efficiency of bronze-steel gearing lubricated with an extreme-pressure lubricant may be somewhat higher than that developed with a petroleum oil, the efficiency is, in general, lower than that obtainable with properly compounded products. The use of extreme-pressure lubricants may even become dangerous in severe service. It has been found that, at the high temperatures generated by worms, some extreme-pressure lubricants will oxidize with surprizing rapidity. One case of such a lubricant becoming solid after 150 to 200 hr. of service has been observed.

Wear measurements carried out on axles in which active extreme-pressure lubricants have been employed, during dynamometer tests, show that some of these lubricants cause accelerated wear and bearing corrosion because of too drastic chemical action. An accelerated form of rusting of steel worms, occasioned by the use of extreme-pressure lubricants, has also been reported.

Greases

The fourth type of lubricant in general use for the lubrication of worm gears is the grease or soap-thickened oil. Greases are manufactured in several types; namely, soda-soap greases, lime-base greases, aluminum-soap greases, lead-soap greases, and mixed-base greases.

Greases are lubricants produced by the suspension of soaps of sodium, lime, aluminum, or lead in mineral oil. Such products may be employed to advantage wherever it is desirable to obtain the flow characteristics of plastics, rather than those of viscous liquids. Being suspensions of a sparingly soluble soap in oil, they are not completely stable, and their consistencies may change in service.

The use of greases appears to be warranted only where it is necessary to prevent leakage from rear-wheel bearings or from worm-shaft bearings. Many bus and truck operators have employed greases successfully over a period of years. However, the costly failures which have occurred in severe service where attempts have been made to employ greases have forced both the axle builder and the petroleum refiner to regard them as unsuitable products for general use.

Three distinct types of failure have been observed in worm axles which have been lubricated with greases. Where loads are heavy, high axle temperatures are set up, and greases manufactured with inferior oils are subjected to rapid oxidation. In severe cases, the oxidation proceeds to such a point that solidification and charring of the lubricants sets in. When this occurs complete destruction of the worm wheel takes place.

Cases have also been observed where stable lubricants of the highest quality have been found to solidify at moderate lubricant temperatures. Investigation of a number of complaints of this type has shown that a small amount of moisture is responsible for the difficulty. Moisture apparently enters the axle during washing operations or during heavy rains, and is rapidly incorporated in the grease. The resulting three-phase emulsion which is formed with certain types of soap is about as hard as ordinary laundry soap and similar in appearance, although darker in color.

A very common type of failure has been observed in the field in cases where high-grade lubricants intended for ball-bearing lubrication and certain lime-soap greases have been employed for rear-axle lubrication. When lubricants of this type are used in worm gears, little difficulty is experienced so long as the lubricant temperatures are maintained below 180

to 200 deg. fahr. However, at the boiling point of water, such greases disintegrate rapidly, separating out oil which soon makes its way to the brakedrums, leaving the worm gear with an insufficient supply of lubricant, which is mixed with the curd-like mass of soap.

As only a few of the more common failures experienced with grease have been mentioned, it is quite evident that the average user will have less difficulty in maintaining the lubrication of his fleet if he employs only fluid oils, than will be the case if attempts are made to employ greases.

Having discussed the physical and chemical characteristics of worm-gear lubricants, and having described the effects of these characteristics upon the life and efficiency of worm gearing, a brief description of the equipment employed in obtaining the test data should not be out of place.

Axle-Dynamometer Equipment

In initiating the investigation, a full-scale-axle dynamometer was constructed by the General Laboratories. This was designed to employ two standard General Electric cradle dynamometers, the one as a source of power, and the other as a means of absorbing the power transmitted by the gearing. The general design and the dynamometer layout are illustrated in Fig. 3. It should be noted that a 100-hp. dynamometer has been selected as the input machine. The power from this dynamometer is transmitted through a long universal-jointed shaft to the worm gear which is mounted in a standard axle housing.

The output machine is a 200-hp. electric cradle dynamometer. This machine is coupled to the worm wheel through a splined driveshaft. It will be observed that the differential of the axle under test is locked and that the drive is through a single end. In studying axles, the angularity of the propeller shaft is adjusted to correspond with that occurring in practice in an average application of the gear wheel under test.

Axle and lubricant temperatures are measured throughout the test by thermocouples. Provision is made for controlling the temperature of the lubricant. The use of a fan blast or a water spray for this purpose has been found to be very satisfactory.

Recently, we have modified the design of the equipment to permit additional test work to be carried out at very high torques and low running speeds. This was accomplished by inserting a speed step-up gear between the wheel shaft and the output dynamometer. At the same time, a larger input dynamometer was substituted to permit development of powers as high as 180 hp. at 1200 r.p.m.

Since the efficiency of this speed-change gear was not constant, it was decided to cradle the axle under test for the purpose of measuring the output torque. This was accomplished by mounting the ends of the axle in large conical roller-bearing trunnions. A beam scale was employed for measurement of the torque reaction of the axle. See Fig. 4.

In a set-up of this type, the motion of the cradle causes a lengthening and a shortening of the propeller shaft. Erroneous scale readings will result if excessive spline friction occurs. The use of a ball-bearing type of spline and provision for a turnbuckle in the scale linkage, to permit leveling of the cradle, is all that is necessary to prevent this type of error. It is, of course, important that the moment of inertia of the cradle be large.

A number of investigators have criticized the use of dynamometers for the measurement of efficiencies of gearing in which the losses are only a small proportion of the total power transmitted. We do not consider such objections to be valid, since the alternate which they propose, the use of a totally suspended cradle, such as that designed by Lanchester, appears to be impracticable where powers of the order of 180 hp. must be dealt with.

To illustrate the application of this dynamometer equipment to the solution of worm-gear problems, the power losses occurring with a number of different lubricants may be measured. In conducting such a series of tests, the input dynamometer is allowed to drive the axle at speeds ranging from 600 to 3600 r.p.m., and the horsepower output and the axle-lubricant temperatures are measured. If no load is applied to the output dynamometer, a curve will be obtained which

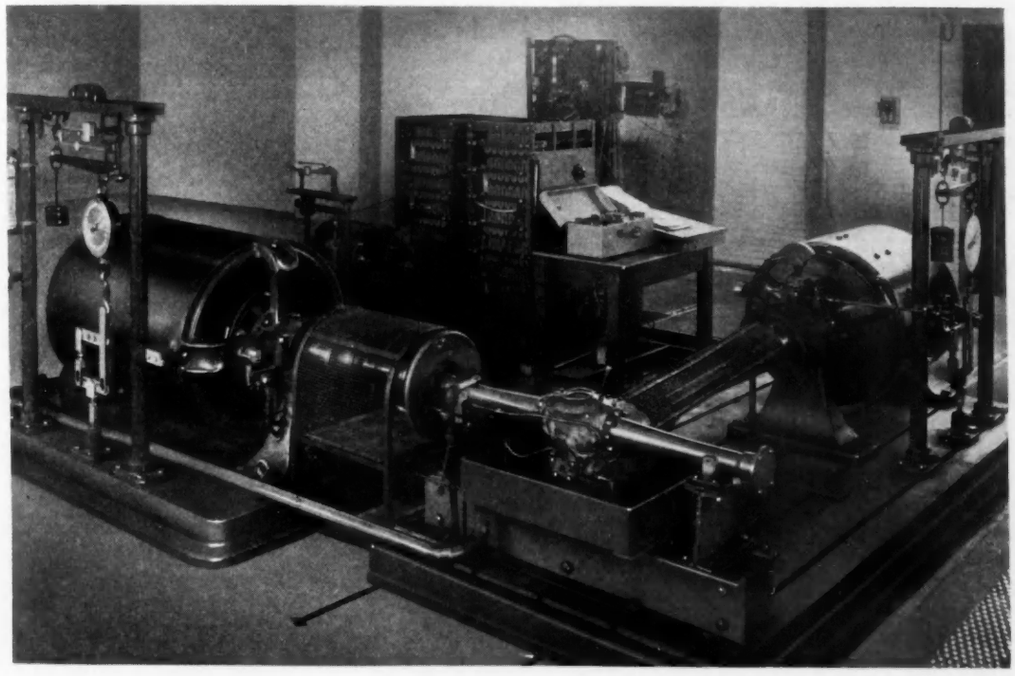


Fig. 3—Dynamometer Set-Up Employed in Studying the Performance of Worm Gears. The Axle Shown is a Nash 1090

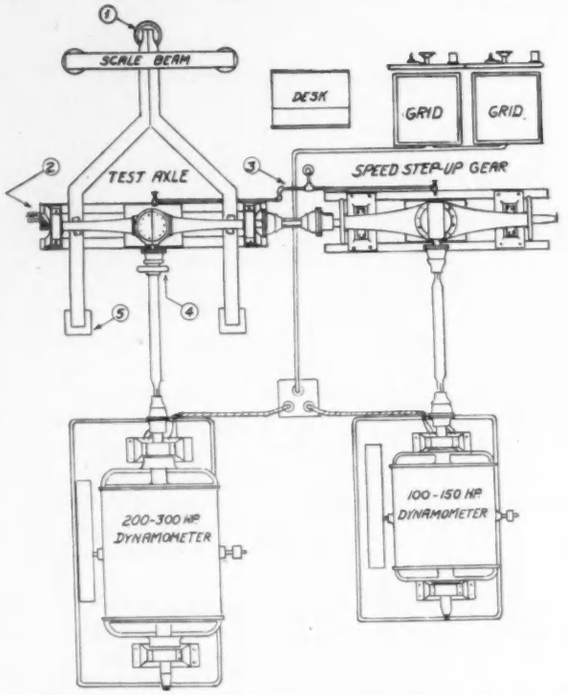


Fig. 4—Plan View Showing the Method of Cradling an Axle for Use with a Speed Step-Up Gear
(1) Dash pot; (2) thermocouple take-off; (3) water supply for spray; (4) ball-bearing slip-joint; and (5) counterweight

illustrates the so-called churning losses produced by a lubricant. The churning losses of a typical petroleum lubricant are shown in Fig. 5. The second curve is a composite curve obtained by plotting the power losses of a number of oils at 3000 r.p.m. against their viscosities at working temperatures.

When a number of lubricants are studied under average conditions of operation, that is, with various loads applied to the output dynamometer, curves such as those shown in Fig. 6 may be obtained. Since all of the lubricants used in this illustration are of approximately the same viscosity, it is evident that the chemical nature of the lubricant is the factor which determines its efficiency in service. That is, products containing large amounts of free fatty acid may be expected to produce more efficient lubricants than will highly refined mineral oils.

If the curve just shown is examined further, it will be observed that there is a marked difference in the coefficient of friction of the worm and wheel when lubricated with various lubricants. However, since these data were based upon runs made at a constant temperature, they do not give a true picture of the gains or losses which will occur in service. More significant data can be obtained on the dynamometer stand by controlling the axle temperatures with a fan blast which is proportional to the air velocity under the car, at the corresponding engine speed. The curves in Fig. 7 were obtained in this manner. This chart illustrates the relation between the efficiency of the gearing, at the several loads, and the temperatures developed by the lubricant.

Inspection of the curve indicates that the differences in efficiency, which were observed under constant-temperature conditions of measurement, are of equally great significance when the lubricant is studied at the temperatures which would be set up by road operation. Further study of the curve leads to the conclusion that Lubricant *D* can be employed at higher power-inputs than are practical with Lubricant *A*. That is, there is a definite limiting loading beyond which Lubricant *A* should not be employed. The second lubricant will permit loading to higher values than the maximum allowable with Lubricant *A*.

This phenomenon was investigated further by making a series of axle-dynamometer tests at constant temperature, but under increasing conditions of loading. If the frictional losses are calculated from data secured in this manner, a family of curves, similar to those shown in Fig. 8, will be obtained.

Examination of the curves in Fig. 8 shows that, at a load of 75 hp., some change occurs in the lubricating action at the tooth surfaces when Lubricant *A* is employed. Oil *L* shows a similar effect at a load of 81 hp., while Oil *D*, which is a castor oil, begins to fail at loads above 90 hp. We know that this condition is occasioned by the incipient failure of the lubricating film at the wheel surface. Operation of the wheel at loads beyond this point is accompanied by rapid surface destruction, hence the sharp rise which occurs after the break in the curve.

Examination of the contact surfaces of the worm wheel, after completion of a series of maximum-torque test-runs, discloses the fact that certain lubricants give a high polish to the wheel, and hence greatly increase its efficiency, while others yield matt surfaces which show lower efficiencies.

Wheel-Tooth Gage

The study of tooth-surface changes and the measurement of the rate of wear of gear parts presents difficulties because the change in shape of the part is generally very slow. The problem becomes complicated indeed when it is necessary to measure gear teeth in position in an axle without disturbing the tooth contact or the bearing adjustments. For this reason it was found necessary to design a special gage for the work. The construction of the device, which finally proved to be successful in operation, is illustrated in Fig. 9.

This instrument consists of a rigid casting which may be mounted upon the housing of a conventional worm-geared rear-axle and located by means of dowel pins. The casting carries a steel shaft set on two trunnions, which are located with reference to the wheel in the same manner as the worm. The steel shaft is fitted with a ball-pointed finger which is located at the pitch circle, and which may be made to

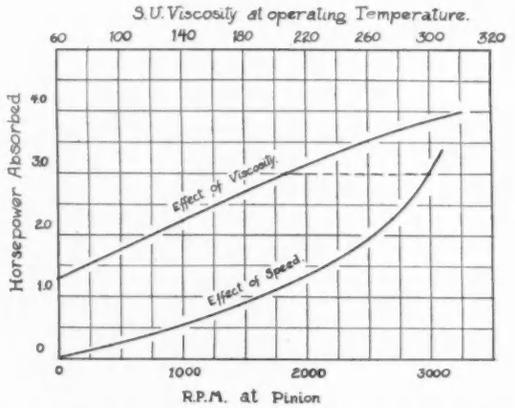


Fig. 5—Curves Showing Churning Losses for a Nash-1090 Axle
The lower curve is for Lubricant *A* at 200 deg. fahr.; the upper curve is a composite of a number of mineral oils at 3000 r.p.m.

traverse a circle equivalent to the pitch circle of the worm. A sensitive dial gage is fastened to the shaft and is fitted with a movable contact finger which follows a cylindrical path along the pitch axis.

In operation, this gage serves to determine the thickness of individual gear teeth at any point along their pitch line. For routine use, a dividing head is fitted to the measuring shaft, which is provided with a five-hole dividing-plate. The holes of this plate locate five measuring positions; namely, right, right center, center, left center, and left. The central position, for example, corresponds to a point on the pitch circle of the tooth at the center line of the wheel. The right-hand position has been selected to fall just within the area of contact near the extreme right-hand edge of the tooth.

The operation of the gage has been highly satisfactory. The dial gage employed in this work has a scale calibrated in 0.0005 in., and can be read to 0.00005 in. However, temperature errors, distortion, and other factors indicate that an accuracy of about 0.00035 in. is about all that should be expected with a gage of this nature.

Measurement of Bearing Wear

Since a large number of the axle failures occurring in service are the result of bearing failure, the rate of wear of all

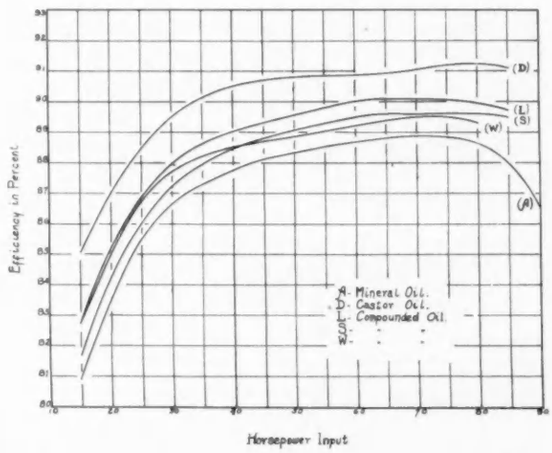


Fig. 6—Power-Input versus Efficiency Curves for a Nash-1090 Axle Operating at 2100 R.P.M. and a Lubricant Temperature of 230 Deg. Fahr.

(*A*) Highly refined paraffine-base bright stock; (*D*) a high grade of castor oil; (*L*) a compounded oil containing 80 per cent of well-refined petroleum-oils and 20 per cent of neutral animal oil; (*S*) a compounded oil containing 4 per cent neutral animal oil and 1 per cent free fatty acids; and (*W*) a compounded oil containing 5 per cent of a less-active animal-oil

bearings employed in the worm-gear tests was determined also.

The measuring gage is of the dial type, but is fitted with two parallel bars at the base. In taking measurements, the gage is first set to a zero reading with a surface plate, then slipped over the bearing. The distance between the ground outer surface of the inner race and the top ground edge of the inner race is determined at five points along the circumference. The inner race is then rotated to a new position, and the measurements repeated. All measurements are made with the bearing under an axial load of 50 lb.

Tooth-Surface Camera

Many methods have been proposed for studying the effect of lubricants upon the surface finish of gear wheels and for

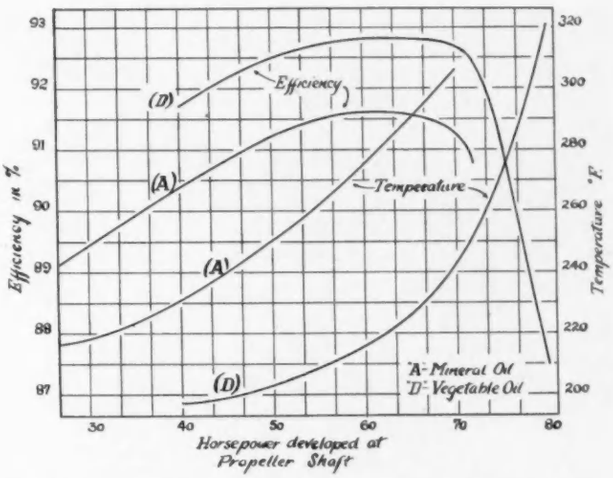


Fig. 7—Temperature and Efficiency Curves under Road Conditions of Operation for a Nash-1090 Axle at 45 M.P.H. and an Atmospheric Temperature of 70 Deg. Fahr.

the investigation of the extent of pitting of gears. Attempts to apply a number of these methods to worm gearing have proved futile. After considerable experimentation, it was found that the needed information could best be obtained by recording the condition of individual teeth photographically. The difficulties encountered can easily be imagined, since it was impossible to disturb the bearing adjustments of the gears, while making the photographs, and since, in the case of the Twin-Coach axle, the camera had to function with the wheel mounted in a housing, in which the only access was through an inspection window 2½ x 2 in. in area.

The problem was solved by the development of a special camera which photographed the teeth, actual size, upon a continuous roll of film. The camera proper was mounted upon a cast-iron jig which also supported an arc light and its optical system. In this way, subsequent photographs were taken under identical conditions of lighting and exposure.

A special locating gage was also constructed, which ensured the proper indexing of the gear teeth before the camera. The instrument in its final form was simple to operate, although the handling of many feet of film and the printing of hundreds of small negatives was in itself a considerable task.

A set of photographs taken with this camera are reproduced in Fig. 15. This set of pictures compares the condition of the same tooth of a 32-tooth worm-wheel at various stages

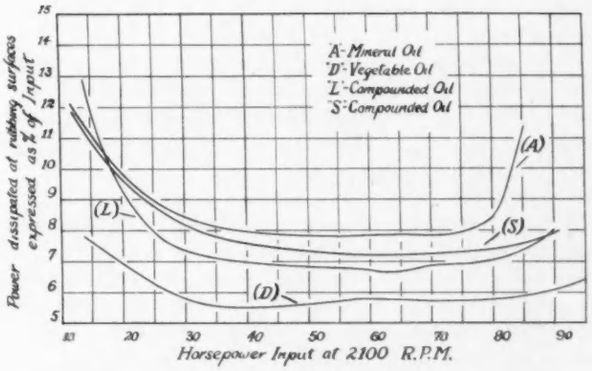


Fig. 8—Power-Input versus Friction-Loss Curves for a Nash-1090 Axle at a Lubricant Temperature of 230 Deg. Fahr.

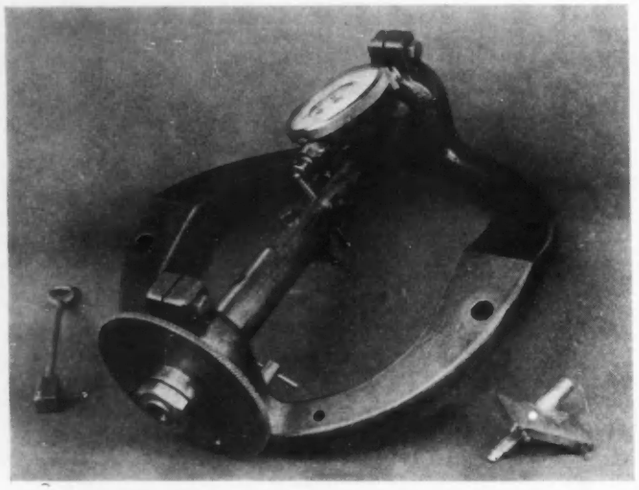


Fig. 9—Tooth Gage Employed in the Measurement of Wheel Wear

of a 225-hr. test-run. The progressive change in the surface finish and the rate of increase in the formation of pits are easily observable.

Since it was particularly important to study the rate of growth of wheel pitting with various lubricants, it was considered essential that an accurate means of measuring their extent be developed. After a number of methods had been investigated, it was found that reliable data could be obtained by integration of the area of pits present in each photograph. This was originally carried out with a standard planimeter. Subsequently, an improved instrument was devised which made use of a ruled measuring glass similar to that used in making blood counts.

Fatigue

Not so many years ago a technical committee was appointed for the purpose of investigating the load-carrying ability of worm gears. The report of this group indicated that the loads to which much gearing could be subjected were almost unlimited. Apparently, some of our automotive designers have memorized the text of that report.

If a moderate-size worm and wheel are mounted upon the test dynamometer and then run at a worm speed of 3000 r.p.m., or 1650 ft. per min. at the pitch circle, provision being made for the removal of heat from the lubricant by the use of a fan blast, it will be found that the gear will easily transmit 90 hp. with a suitable lubricant and that, under favorable conditions, 110 hp. can be transmitted with little indication of tooth scuffing.

This result, which is in line with the findings of the committee referred to, indicates that the petroleum refiner, at least, would not object greatly to the increasing of present worm-gear loadings. However, if this same gear be operated for 100 hr. at only a 60-hp. load and its performance and that of the lubricant be studied, several new facts will be brought to light. While a poor lubricant may fail under such an accelerated test, little change occurs in the more stable lubricants. However, Figs. 10 and 11, which illustrate the condition of the tooth surfaces of the worm and wheel after many thousand miles of service, tell a very different story. In these photographs, we note that the metal far below the surface of the gear has failed as a result of compression fatigue. This type of failure is commonly described as pitting.

The once mysterious worm-gear failure which has caused so much trouble in the past appears, in the light of such tests, to be a simple problem in metallurgy. The nature of these failures is illustrated further in Fig. 16. These photographs show individual teeth of a gear during several thousands of miles of operation under sustained load. It will be observed that some teeth are almost free of pits, while the contact surface of others is nearly destroyed. In Fig. 12, in which the area of each tooth pit has been plotted against the tooth number, it will be noted that a curve is obtained rather than a random scattering of points.

Since the same lubricant was used on all of the teeth, it is evident that there is some factor influencing pitting which is associated with the position of the teeth on the wheel. In Graph No. 1 of Fig. 12, where the pitting bunches about tooth No. 17, the shape of the curve suggests that the wheel had been mounted off-center, or that the casting had been unequally chilled. Metallurgical microphotographs would appear to support the former conclusion.

The second curve, Graph No. 2 of Fig. 12, is a rather rare one which has never been encountered in our laboratory but which we understand was once common in practice. Here every fifth tooth is pitted, the others being nearly perfect. The pitting is obviously the result of some imperfection in the spacing of the worm, which had five leads. This leads to the important deduction that pitting may be aggravated by mechanical errors which attempt to cause acceleration of the wheel at some point in the cycle. Such factors as unbalance, uncorrected angularity of universal joints, bent propeller shafts, and similar causes must, of course, be considered.

Some fleet operators believe that worm-and-wheel fatigue is the result of lubricant failure. Our researches have shown conclusively that surface pitting is a metallurgical failure, and

Fig. 10—A Worm That Failed as a Result of Compression Fatigue

Fig. 11—A Pitted Worm Wheel

that the amount of surface pitting produced by all high-grade worm-gear lubricants is approximately the same. It is only when the lubricant fails completely as the result of excessive oxidation, low temperature, channeling, or from other causes, that the blame for excessive pitting can be placed upon the lubricant. This conclusion was reached after analyzing the results of a comprehensive investigation of the influence of lubricants upon the mechanism of pitting. The curves in Fig. 13 summarize a few of the results of the investigation of the effects of lubricants upon worm-gear fatigue.

In obtaining these data, a standard Twin-Coach wheel was set up, and the rate of pitting and of tooth wear measured after operation upon a variety of lubricants. It will be observed, that, as would be expected, the rate of pitting of the wheel increased with its age. However, with one exception, we find that all the points fall upon a smooth curve. That is, a change of lubricant did not appear to affect the rate of pitting, since, in this test, two very different lubricants yielded about the same relative amount of pitting.

It will be observed, however, that an actual decrease in the area of pits occurred with Lubricant *B*. This fact would appear to contradict the statement just made. The dash-line curve in Fig. 14 supplies a clue to the reason for the reduction in the area of surface pits when Lubricant *B* was employed. This curve, which shows the rate of tooth wear, is a smooth curve which breaks sharply at the point corresponding to the introduction of Lubricant *B*. Hence, it is very evident that Lubricant *B* did not reduce the rate of pitting materially, but that it did permit the surface of the tooth to wear away as fast as the pits formed, uncovering fresh unpitted surfaces.

The mechanism of pitting is illustrated in Figs. 15 and 16. These pictures show the changes which occurred in the surface condition of the individual teeth of the gear during the course of the 225-hr. test-run. The numbers employed are arbitrary numerals designating the position of the tooth on the wheel. The letters correspond to the intervals at which inspections were made throughout the test.

For example, photographs 13-*A*, 13-*B*, and 13-*C* in Fig. 16 illustrate the change in the surface condition of Tooth No. 13, during the first test run of 50-hr. duration. Photographs 13-*D* and 13-*E* illustrate the changes which occurred when the test run was continued with a second lubricant, Lubricant *F*. The letters *A* to *I* in Fig. 14 designate the intervals at which photographs were taken. Similar photographs obtained from other teeth of the same gear are illustrated by the series numbered 1-*A* to 1-*I* in Fig. 15.

These photographs are particularly interesting in that they illustrate the manner in which the pits spread and show the relation of the pitted areas to the contact surfaces of the wheel. The *I* series of photographs is rather unusual. The effects of the rapid tooth wear, in cutting away the pitted

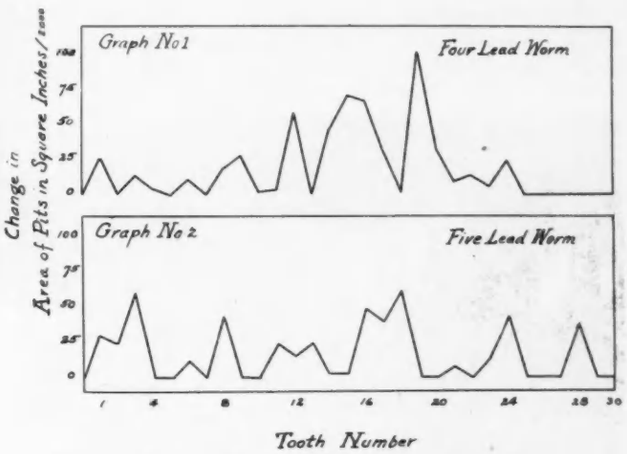


Fig. 12—Curves Illustrating That Some Factor Influences Pitting Which Is Associated with the Position of the Teeth on the Wheel

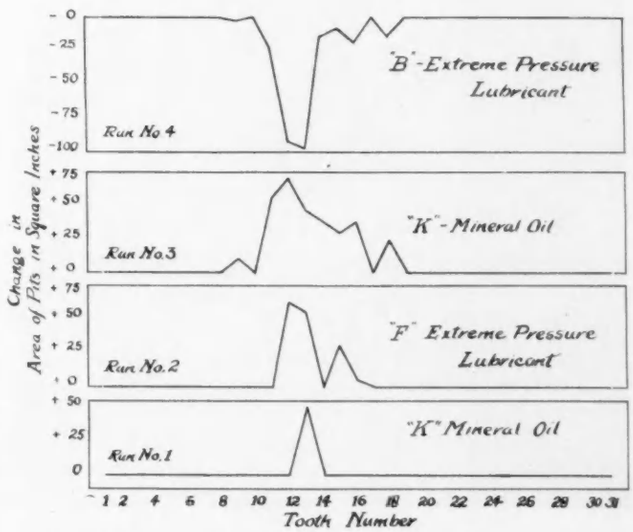


Fig. 13—Curves Showing Change in Surface Area of Pits Formed upon Individual Wheel Teeth During Runs with Various Lubricants. Twin-Coach Axle; 2200 R.P.M.; Load, 60 Hp. at 200 Deg. Fahr.

surface metal, are particularly noticeable. In a few of the photographs, a definite ridge may be observed, which shows the depth to which the tooth has been worn away.

The photographs clearly illustrate the fact that, although certain specialized lubricants may prevent tooth destruction in the case of extreme overloads, in ordinary practice all really good lubricants hold the rate of pitting to the minimum practicable. The tests used as illustrations were all run at constant temperature. Referring again to Fig. 7, it will be noted that the lubricant temperatures developed in an axle on the road may show differences of as much as 60 deg. fahr. when good and poor lubricants are compared. Since all the physical properties of bronze change with temperature, it is reasonable to expect that continued operation at high lubricant temperatures will hasten metallurgical failure.

The series of test runs described previously were made with a single gearset. The five series of test runs discussed in the summary were made with five similar sets of worm gears of the type developed for the Nash 1090 axle. New anti-friction bearings were used with each set. In general, the results of both series of tests are in good agreement.

A detailed summary of the chemical and physical changes which occurred in the various lubricants during the test runs, which were of 9200 miles duration and were carried out at a speed equivalent to road operation at 65 m.p.h. under a load of 60 hp., appears in the Appendix.

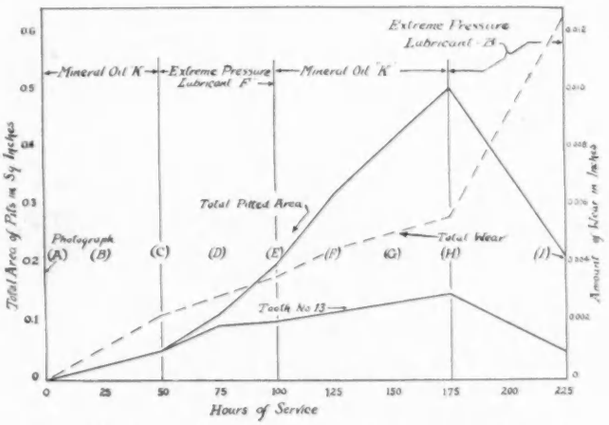
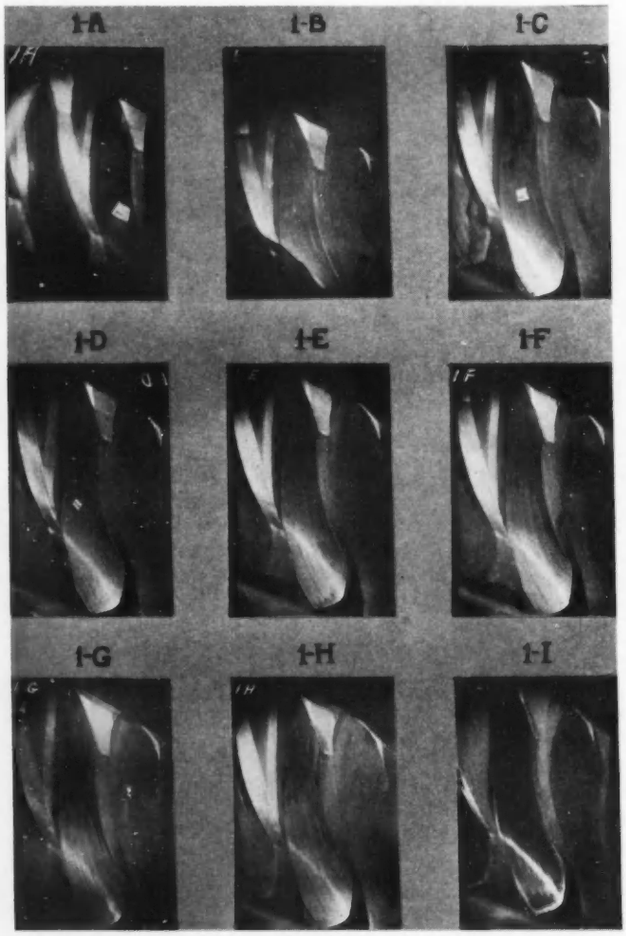

Extreme Pressure Lubricant "B"
Mineral Oil "K"
Extreme Pressure Lubricant "F"
Mineral Oil "K"
Total Pitted Area
Total Wear
Photograph (A) (B) (C) (D) (E) (F) (G) (H) (I)
Tooth No 13
Total Area of Pits in Sq Inches
Amount of Wear in Inches
Hours of Service
0 25 50 75 100 125 150 175 200 225

Fig. 14—Curve Showing Rate of Pitting and Tooth Wear of a Twin-Coach Worm-Wheel During Operation with Various Lubricants. Speed 2200 R.P.M.; Load, 60 Hp. at 200 Deg. Fahr. (K) Refined Mid-Continent Petroleum Oil; (F) Mild Extreme-Pressure Lubricant; and (B) Active Extreme-Pressure Lubricant

Fig. 17 illustrates the differences in the rate of wear ob-



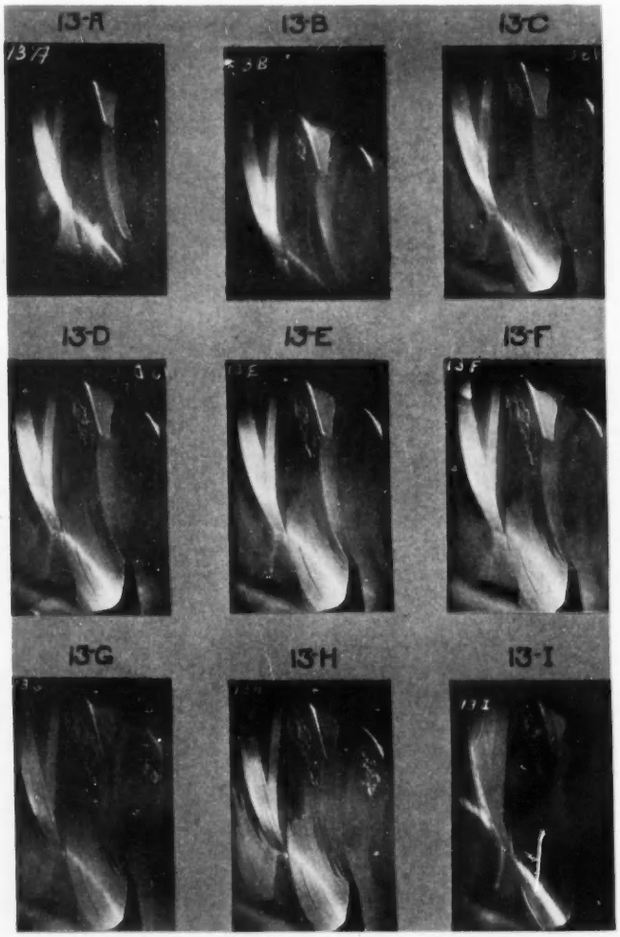


Fig. 15—(Left) and Fig. 16 (Right)—Single-Tooth Photographs Indicating the Surface Changes Which Occurred During a 225-Hr. Test-Run

The numeral is the number of the tooth of the gear. The letter designates the period at which the photograph was taken. The letters employed correspond with the letters used in Fig. 14

tained with the lubricants employed. It will be noted that the wear with the chemically active Lubricant *B* was about five times that of a good mineral oil. Even castor oil, which produces high surface polish on the wheel teeth and shows the highest efficiency, produces three times the amount of wear of the mineral oil. This would appear to indicate that the chemical action was responsible for the rapid polishing action of the castor oil.

While the high rate of wear produced by the use of Lubricant *B* might be tolerated under certain conditions, the corrosion which its chemical activity induces has prevented its commercial use.

The undesirability of employing corrosive materials as gear

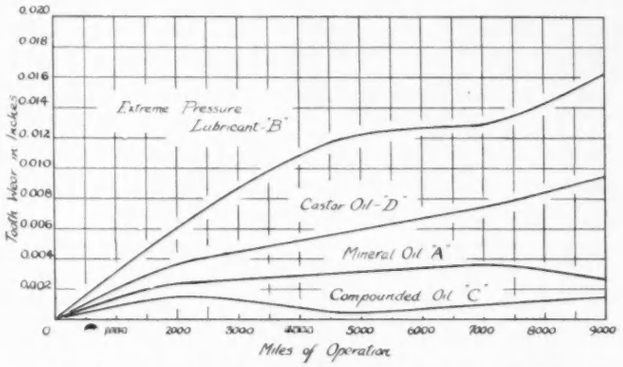


Fig. 17—Curves Showing Rate of Wear of Four Identical Worm Wheels Lubricated with Four Types of Lubricant. Timken Worm and Wheel Operated at 60 Hp. and 65 M.P.H. and a Lubricant Temperature of 230 Deg. Fahr.

lubricants is conceded by all lubrication engineers. Despite this fact, frequent field failures are reported which have been traced to the liberation of free acids during service. Fig. 18 illustrates the conditions of a steel worm which had been

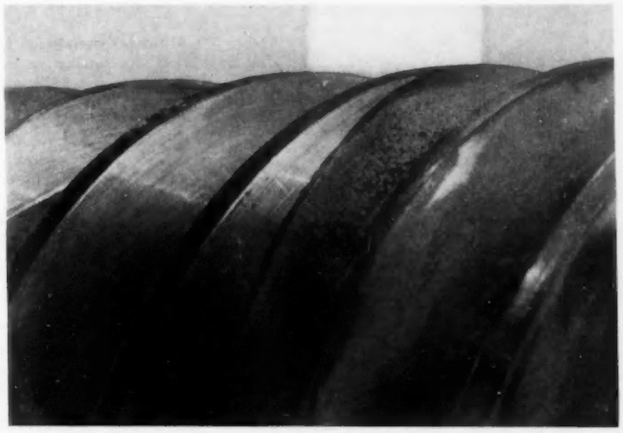


Fig. 18—Worm Corroded by an Active Extreme-Pressure Lubricant Containing Chlorine

employed with this strongly chlorinated lubricant. Similar corrosion of anti-friction bearings is believed to occur in the field where similar products are being experimented with.

The present paper has attempted to explain some of the lubrication requirements of worm gears and has pointed out the influence of the various types of lubricant upon performance. Perhaps the most important fact revealed by the investigation is that both the petroleum industry and the automotive industry must work together if better worm gears and better worm-gear lubricants are to be made available. Some of the most serious of the service complaints, such as that of excessive pitting of wheels and worms, can be eliminated only by the automotive designer. The lubrication engineer, on the other hand, can be of assistance in smoothing over the difficulties which arise if he will point out to the manufacturer and to the operator the abuses which are responsible for field difficulties.

Appendix

The preceding report described the results secured from dynamometer tests of a number of worm axles when lubricated with various types of materials. Reference has been made in the paper to the classification into which each lubricant falls. In Tables 3 and 4, the chemical and physical characteristics of the lubricants studied are given in detail. The nature of the service changes which occurred in the case of each product are also reported.

Table 3—Comparison of Physical and Chemical Characteristics of Lubricants Employed in Axle Tests with Characteristics After Use

Lubricant Composition	(140 Hr. of Service—Nash-1090 Axle—60 Hp. at 65 M.P.H.—230 Deg. Fahr.) *A* Highly Refined Mineral Oil		*B* Active Extreme-Pressure Lubricant		*C* Compounded Oil[a]		*D* 100 Per Cent Vegetable Oil	
	New Oil	Oil After Test	New Oil	Oil After Test	New Oil	Oil After Test	New Oil	Oil After Test
Gravity, Deg. A.P.I.	23.6	22.7	22.3	21.0	23.2	22.4	15.0	14.2
Flash, Deg. Fahr.	515	525	480	450	515	475	495	460
Fire, Deg. Fahr.	595	595	590	560	590	590	595	570
Pour, Deg. Fahr.	20	..	10	15	5	..	0	0
Vis. Say. Univ. Sec. at 130 Deg Fahr	1055	1187	1023	1293	996	1154	486	645
Vis. Say. Univ. Sec. at 210 Deg. Fahr.	152	166	160	171	146	160	96	118
Color (N.P.A.)	Dk. 7	..	8+	Black	Lt. 8	..	Lt. 2	Dk.Green
A.S.T.M. Tar, Per Cent.	Zero	Trace	Trace	5.75	Zero	Trace	Zero	Trace
Conradson Carbon, Per Cent.	1.74	..	1.77	4.83	1.78	..	0.12	0.49
Neutralization Number	..	0.48	2.42	1.10	1.58	0.90	10.95	10.60
Ash, Per Cent	Trace	0.03	Trace	1.67	Trace	0.10	Trace	0.63
Sulphur Content	None	..	0.94	0.57	None	..	None	..
Chlorine Content	None	..	0.70	0.55	None	..	None	..

[a] Contains ½ per cent active synthetic fatty acids; 2 per cent glycerol ester.

Table 4—Characteristics of Lubricants Employed in Axle Tests

Lubricant		*K*	*F*	*F-2*	*L*	*S*	*W*	*X*
Composition		Refined Mineral Oil	Mild Extreme-Pressure Lubricant	Mild Extreme-Pressure Lubricant	Compounded Oil 20 Per Cent Neutral Animal Oil 80 Per Cent Mineral Oil	Compounded Oil 1 Per Cent Free Fatty Acids 4 Per Cent Animal Oil	Compounded Oil 5 Per Cent Animal Oil	Soap Thickened Oil[a]
Gravity, Deg. A.P.I.		22.2	21.0	21.6	24.9	25.9	25.7	....
Flash, C.O.C., Deg. Fahr.		550	545	510	530	515	550	....
Fire, Deg. Fahr.		635	640	585	600	595	625	....
Pour, Deg. Fahr.		20	60	5	40	35	25	....
Vis. Say. Univ. Sec. at Deg. Fahr.	100	....	....	....	....	....	....	A.S.T.M. Cone Penetration 350 mm.
	130	....	....	957	639	722	785	
	210	177	190	168	134	133	145	
Color		Green	Dark Green	Dark 8	Green	Dark Green	Dark Green	Green
A.S.T.M. Tar, Per Cent		Zero	Trace	Zero	Zero	Zero	Trace	....
Conradson Carbon, Per Cent.		2.68	....	1.66	1.73	....	2.35	....
Neutralization No.		0.02	0.46	0.20	0.10	1.10	0.09	Neutral
Sulphur Content, Per Cent		....	1.23	1.01	....	....	....	....
Film Strength, Almen		....	9,000	8,500	....	....	....	....
Soda Soap, Per Cent		....	....	....	....	....	....	7.25
Mineral Oil Per Cent		....	....	....	....	....	....	92.75

[a] Mineral oil used is identical with Product *K*.

Discussion of Schlesman Paper

Constructive Criticism On Important Points

—**Roland V. Hutchinson**

REFERRING to Fig. 6 of the paper, the efficiencies reported are appreciably lower than has been my experience with other axles of comparable size and ratio, though the shapes of the curves check with my experience.

(2) Referring to Fig. 5 of the paper, the term "churning losses" seems to have been confused with the more exact term "loss when transmitting zero power," which latter includes the former.

If there were no losses existing, then the input torque on the wormshaft would equal wormshaft thrust times center distance; hence I have found it more convenient to analyze in terms of lost worm-thrust to setting-up conditions plus that due to pure churning losses.

The fixed loss has, for gearsets up to 8-in. centers or so, a fairly wide variation in numerical value, and, translating into terms of horsepower, (to keep in step with Dr. Schlesman) seems to vary as follows:

$$2 \times 10^{-4} \frac{SC}{R} < \Delta Hp_F < 8 \times 10^{-4} \frac{SC}{R}$$

where

ΔHp_F = lost horsepower due to fixed lost thrust
S = wormshaft speed, r.p.m.
C = center distance, in.
R = reduction ratio expressed as a whole or as a mixed number

If ΔHp_o = lost horsepower at zero transmitted power, and ΔHp_c = lost horsepower due to churning, then

$$\Delta Hp_c = \Delta Hp_o - \Delta Hp_F = KS^n$$

where K is a scale factor, and the exponent n is close to 3 in numerical value.

(3) Concerning the stability of the several oils and their comparison in Table 1, Fig. 8 of the paper gives losses at constant temperature and constant speed independently, varying input horsepower. Since the heat generated within the axle must be dissipated by heat rejection from the case, it is fairly clear that, for constant speed, load and environment conditions, the equilibrium temperatures obtaining with different lubricants will likewise differ, being higher when efficiencies are lower.

Since rate of production of "oxy-products" may be accelerated by increases of oil temperature as well as by the ratio of exposed surface of the churned-up oil to its volume, would not a more equitable comparison of stability ensue were the several oils compared at temperatures above environment more nearly proportional to the experienced losses as depicted by curves of the nature shown in Fig. 8?

(4) Concerning bearing wear, all axle bearings are preloaded when set up. The amount of pre-loading is jointly established by the rigidity of the mounting and by the man who does the actual assembly. Over the first a reasonable control exists; over the second, virtually none. For manufacturing convenience, housings are checked for alignment in the unloaded condition. Because of pre-loading and of housing elasticity, the resultant elastic deformation of the housing is reflected in non-uniformity of internal loading of the wheel side bearings.

Small dimensional changes are being measured. To mean anything really, these measurements must be made on many similar sets of parts assembled alike as to dimension and preload, before safe conclusions may be drawn. This appears particularly true when considered in connection with paragraphs (2) and (3) of this discussion.

Main Points in C. C. Minter's Paper Analyzed by Prominent Discussers

MR. MINTER'S paper on Flame Movement and Pressure Development in Gasoline Engines, which was read at the 1935 Annual Meeting in Detroit, was published in the S.A.E. JOURNAL, March 1935, beginning on page 89. He defined combustion roughness as the ratio of the rise in pressure to the time required for the burning, and pointed out that the time required to burn a charge in an engine is directly proportional to the volume of the charge.

The paper considers the question of how flame speed varies during the burning, and brings out that it goes through a maximum when half the volume of the charge is burned. Further, that the exact location of the point of maximum flame speed will depend on the clearance volume and the compression pressure.

Method and Machine for Avoiding Combustion-Chamber Calculation

—Alex Taub

Development Engineer, Chevrolet Motor Co.

THERE is a great deal in Minter's paper that is to be appreciated by the designing engineer, not the least important being the obvious effort to make himself clear. There is a willingness here that is much needed. Designing engineers freely admit that progress must come through the chemist; however, it will never come until we who must adapt understand the principles involved in the proposed progress. Therefore, we appreciate any effort to help us understand the physical-chemical viewpoint.

We concur with Minter that Janeway's major contribution to the predetermination of combustion roughness was his development of volume distribution. Having been associated with Janeway prior to 1927, when he struggled through his maze of mathematics to the present principle of volume distribution, we are more than delighted to find confirmation among the physical chemists.

Volume distribution has to do with the business of determining how the volume of the combustion chamber is distributed about the spark plug. This development became a possibility upon the determination of two assumptions:

(1) That the volume of each flame front is part of a sphere centering at the spark plug. This means that the flame front advances in the general form of a sphere. This fact has been substantiated for all practical purposes by investigators all over the world.

(2) That the volume of each progressive flame front may be calculated or determined, assuming that the piston is stationary at top dead-center. This assumption we will prove later.

Mr. Janeway carried his volume-distribution principle much further than establishing the actual distribution of the volume. He combined with this some outstanding thermodynamic developments, which enabled him to predetermine from these data theoretical indicator cards, from which Janeway carried forward his famous theory, to wit: That the effect of the acceleration of the pressure rise was the actual roughness factor. Janeway developed constants for this work from actual indicator cards; however, he admitted that these constants would vary with different engines.

Mr. Minter has taken definite issue with Janeway, although appreciating the importance of his work. Minter states that the flame velocity goes through a maximum when 50 per

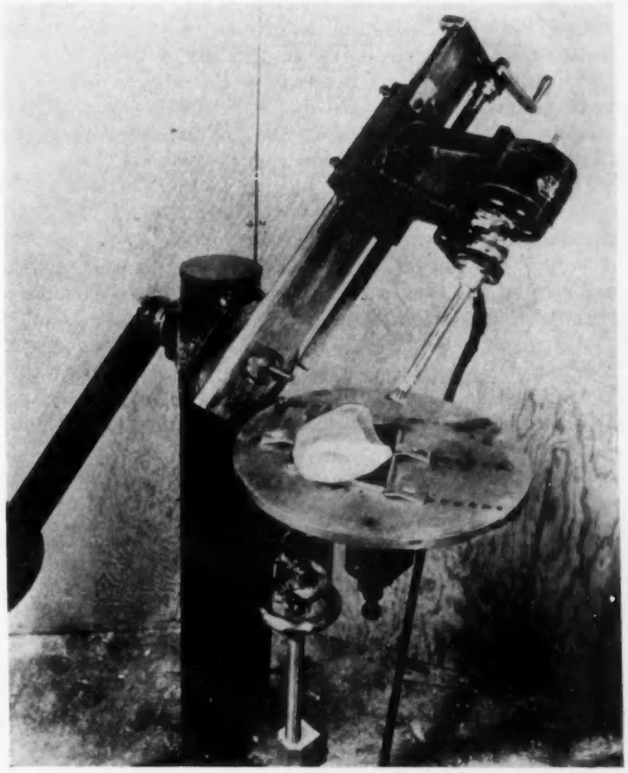


Fig. 1—Machine for Spherical Sectioning of Combustion-Chamber Plaster-Casts

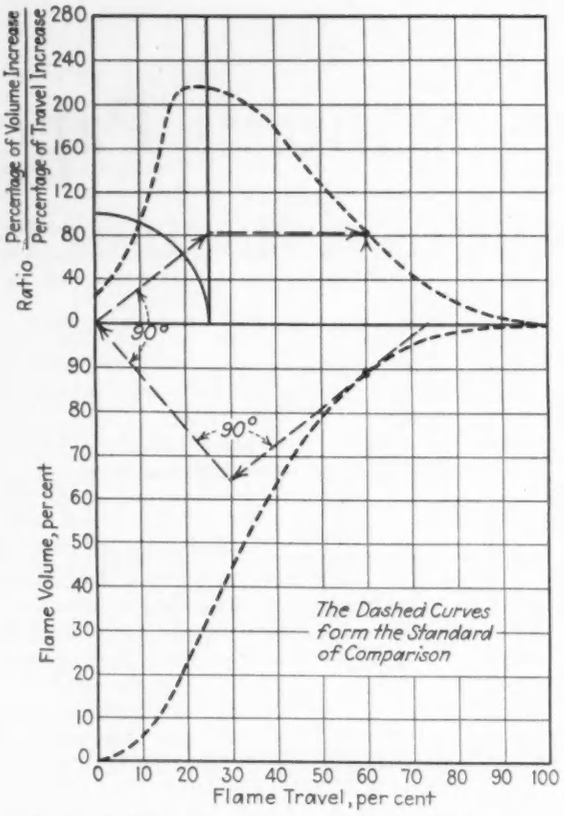

Ratio Percentage of Volume Increase / Percentage of Travel Increase
Flame Volume, per cent
Flame Travel, per cent
90°
90°
The Dashed Curves form the Standard of Comparison

Fig. 2—Original Chevrolet Chart Showing the Method of Deriving the Rate Curve

cent of the volume is burnt, from which point there is a falling off. This, according to Minter, means that superimposed upon the pressure-rise acceleration is an accelerating and decelerating factor that would be exceedingly difficult not to consider. We would add that it would be just as difficult to consider. Mr. Minter points out that this speeding up and dropping off varies with different chambers.

Of late we have felt that all was not well with the principle of depending upon pressure-rise acceleration as the sole determining factor of comparative quality of combustion chambers. Minter's statements serve to confirm this opinion, and certainly do cast some doubt upon Janeway's principle or criterion that depends on the acceleration of pressure rise.

We are on record as supporting Janeway in his work on combustion chambers, and still do. We have been happy, and still are, in following his original principles as developed by him when he operated under the banner of General Motors.

Janeway, the perfect mathematician, never recognized drudgery, and therefore he felt it was no job at all to calculate every theoretical step taken by the theoretical flame front. At Chevrolet, we have always felt that the real benefit of any development is not obtained until the principles can be made a drafting-room routine.

To obtain the most out of any combustion chamber, it is necessary to determine the roughness characteristics of from eight to twelve plug positions. Thus, one can be sure of the best combination. Designers are not noted for their infinite patience, nor for their outstanding knowledge of thermodynamic practice; hence, if we were to get the most out of each combination, through designers, long tedious calculations were out of the picture. We therefore sought a simplification of the process by reconsideration of the entire structure.

Acceleration of the pressure rise did not cover the many variables between engines. Different compression ratios require different criteria. Increased output due to volumetric was not covered. Acceleration of the pressure rise just did not cover the ground.

The one fundamental principle of volume distribution that stood out beyond criticism, was the obvious fact that the rate of pressure rise must in some degree follow the amount of mixture available to burn in any one instant. Therefore, the actual volume distribution alone should be made to tell all of the story, or at least all that is necessary to tell, without recourse to theoretical time-pressure curves, whose accuracy is at best doubtful. Now to eliminate the drudgery of calculation. If this could be done, we could obtain the necessary evidence to set up a worth while bogey.

Since the flame front moves as a sphere, a machine was made that would cut plaster casts of combustion chambers by spherical sections. The amount at each cut can be readily determined by several routines.

Fig. 1 is a machine designed for this purpose consisting of a small turntable with a swinging cutting arm. The cut begins with the spark plug as a center. It is a simple matter to move the turntable relative to the cutter, thus having the effect of as many spark-plug positions as one may have plaster casts. Thus we are able to obtain data quickly and cheaply by routine, and in any quantity desired. Now to record the data, because these, after all, are the result; the cutting machine is but a means to an end. Mr. Samuels, the mathematician of the Chevrolet Engineering Department, who undoubtedly ranks with any in the country, developed a chart that gave us our beginning.

Fig. 2 is a construction chart showing how to plot the data obtained from the cutting machine. This chart is divided into two parts, upper and lower. The lower part is the exact record of the distribution of volume. The flame travel in per cent is plotted against the per cent of volume burnt at any position. The curve obtained gives a picture of the variation in rate of the volume burnt for a given flame-front movement. This can be more graphically set forth by plotting the ratio of volume burnt to the distance traveled in the form of a curve, such as is shown in the upper curve.

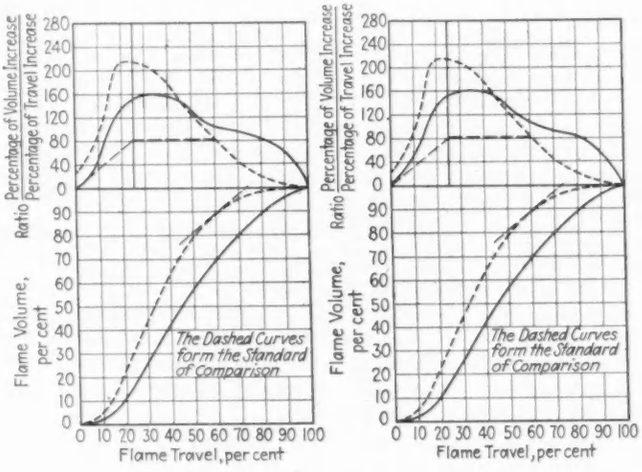

Ratio Percentage of Volume Increase / Percentage of Travel Increase
Flame Volume, per cent
Flame Travel, per cent
The Dashed Curves form the Standard of Comparison
Ratio Percentage of Volume Increase / Percentage of Travel Increase
Flame Volume, per cent
Flame Travel, per cent
The Dashed Curves form the Standard of Comparison

Fig. 3—Showing That Combustion Chambers' Flame-Front Areas May Be Calculated with the Piston at Dead Center

The curves at the right are corrected for piston movement.

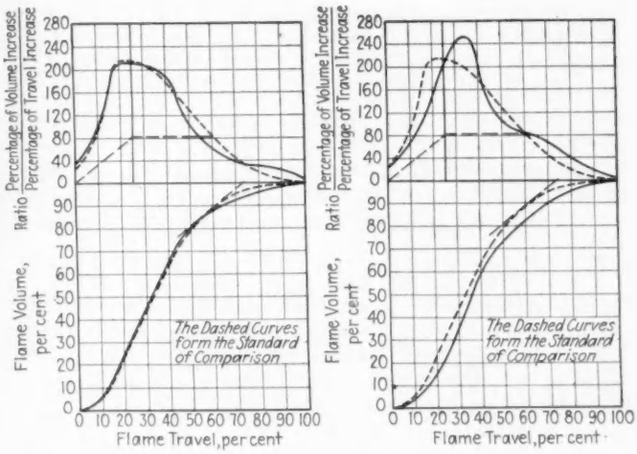

Percentage of Volume Increase
Ratio
Percentage of Travel Increase
Flame Volume, per cent
The Dashed Curves form the Standard of Comparison
Flame Travel, per cent

Fig. 4—A Good Job Is Shown at the Left, and a Rough Job at the Right

This curve, in keeping with the simplification of the process, is plotted by transferring the actual tangents as indicated in the construction lines. The relative scale is important when using transferred tangents.

A vertical construction line is located in the upper chart at a distance equal to 100 per cent of the vertical height. All tangents intersect this line, the intersection representing the vertical height of the point on the upper curve, which is the rate curve. The point of original tangency gives the horizontal position of the point, and so the curve is plotted. Altogether, very little practice is required to acquire a good and quick hand at this business. The result is the rate curve which is the instrument, if you will, that must be used to make roughness comparisons.

With a machine that eliminated the drudgery and with a terrific saving in time, and a chart for making records, it was a simple matter to obtain plaster casts of many different types of combustion chambers. By rating each car for smoothness with proper discount for oversoft mountings and retarded spark, and cutting up a plaster cast of each combustion chamber, it was a simple matter to pick a tentative ideal shape. This shape is indicated in the original curves, and was used as a bogey while data were collected to establish a more certain and accurate criterion.

The important fact about this rate curve, which is the upper curve in the chart, is the location and extent of the maximum rate point. Obviously, the rate must have a limited maximum, and it should be obvious that the location of this maximum rate with reference to flame travel is important.

Flame travel represents burning time, and may be divided into three zones of first 3rd, second 3rd, and last 3rd. This is how, in our work, we are accustomed to view the combustion problem. Like a shoemaker putting the last first, we know that the last 3rd is the area of detonation control, since here detonation does occur. The first 3rd we consider the heat-loss-control area, because this is the only area in which one can do anything about it; but that is another story. The middle or second 3rd is the roughness area, because, in this area, roughness will occur.

The first 3rd contains too little volume to affect roughness. During the last 3rd, the piston is receding and thus is not readily affected. But during the middle or second 3rd, the volume is high and the piston is approaching or at top dead-center, and therefore is sensitive to shock. The maximum rate should be well within the first 3rd.

The bogey set up in the original charts, we are pleased to say, represents an early Janeway combustion chamber, selected because of combustion smoothness and our knowledge that it would be well done, and because it was of a type that we were acquainted with through our early association with combustion chambers and Janeway. It represented a satisfactory combination of output and compression ratio.

Before proceeding further, it would be well to establish the validity of the assumption that combustion-chamber analysis could be made assuming that the piston is standing still.

William Samuels was given the tough assignment of calculating the Chevrolet combustion chamber, allowing for piston movement. Each step in flame movement was determined in percentage of a volume that varied with each position of the piston. This was compared to a similar calculation, assuming that the piston was stationary. Fig. 3 shows a comparison of these two results. It is seen by the full line that there is no difference at all. The dotted lines represent the bogey.

We do not know whether Janeway made these laborious comparisons in determining this important assumption; we doubt it. We are satisfied that the assumption was made, and we know it was correct.

It is impossible to show all of the many results that have been obtained by the Chevrolet Engineering Department since using this simplified process of combustion analysis; however, some interesting comparisons are worth making.

Fig. 4 shows two results: the left-hand chart was from an engine that was outstandingly smooth; the right-hand chart was from an engine that was inherently rough. Note how closely the smooth result matches the bogey. Yet these combustion chambers have absolutely nothing in common as to

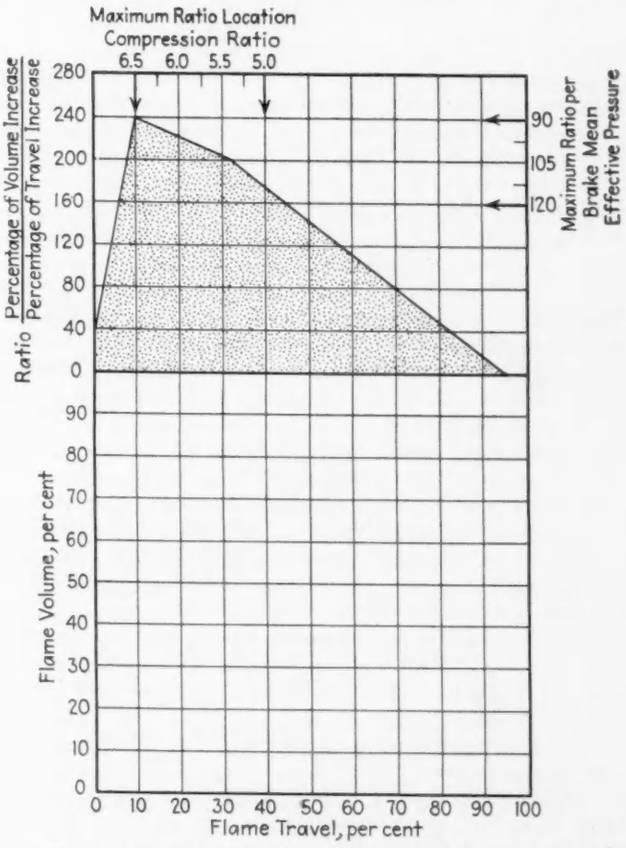


Fig. 5—Chevrolet's Combustion-Chamber-Routine Chart

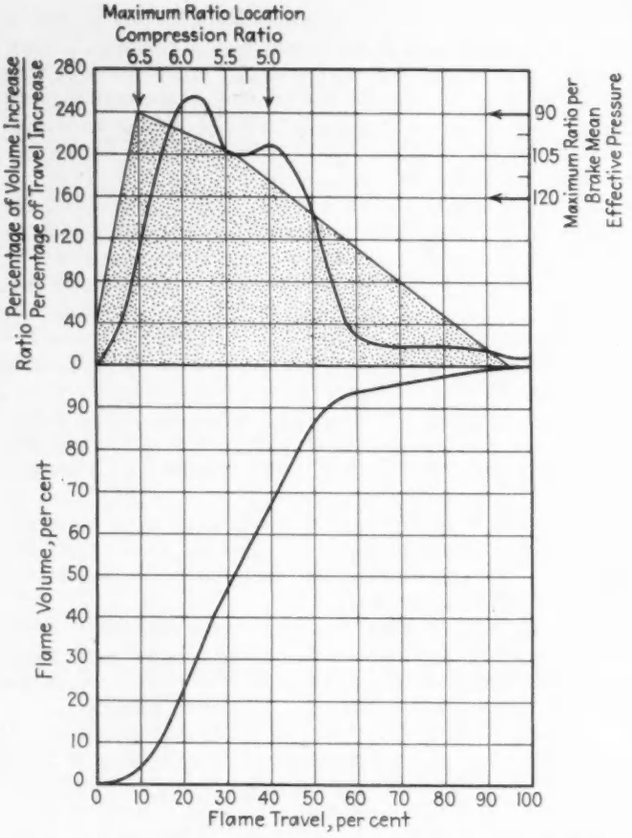


Fig. 6—Showing a Bad Result Requiring a Lot of Rubber or a Retarded Spark

shape; in fact, were this chamber taken by itself and without analysis, it would be estimated as being too compact for smoothness. On the other hand, the chamber indicated in the right-hand chart as being rough is much less compact and would be estimated as being smoother than the left-hand chart result. This indicates a truth. One cannot see a combustion chamber shape by looking at it, one must section it. There is only an apparent shape, which, although important, may be easily spoiled by a poor spark-plug location. So far, so good; but far from good enough, for yet a true criterion has not been established. No one point or line can ever be correct for combustion-roughness comparison.

The location of the maximum-rate point relative to the flame travel (the maximum rate being after all the maximum flame-front area) is very important; but it can never be in any one position, since it must vary with compression ratio.

Spark advance varies with compression ratio, being shorter as the compression ratio increases. This means that the top-dead-center location is closer to the initial burn as the compression ratio increases. Therefore, the maximum-rate position must vary with the compression ratio, moving to the left of the chart. Thus, simply stated, the greater the compression ratio is, the shorter is the distance that the flame front must travel to arrive at its maximum area, and must decrease from this point on.

Fig. 5 shows the chart as now used in Chevrolet's combustion-chamber routine. It also incorporates two charts; the lower being direct data on volume distribution, and the upper curve being the rate curve obtained as described for Fig. 2. This chart incorporates a shaded area, which indicates the area that the rate curve should not exceed. There is also incorporated a scale that indicates where the maximum rate should be for a given compression ratio. Thus a criterion is established that covers this variation. The actual values are based on experimental experience. All are welcome to establish their own values.

Another important variation not considered in any other system of analysis is power output. Yet it is well known that engines roughen up as the brake mean effective pressure is increased.

Fig. 5 takes care of this variation by allowing for it. The ratio of volume burnt to the distance traveled has a definite value, and it is this value that must vary as the output in B.M.E.P. is increased. A B.M.E.P. scale is given for this variation in output. Again these actual values are based on years of experimental experience.

From the foregoing we submit that the criterion for combustion roughness is a moving target, wherein the maximum rate of volume increase, or maximum flame-front-area position relative to flame travel, varies with compression ratio. Also that the maximum volume rate which is the maximum flame-front area must decrease as B.M.E.P. goes up.

Any criterion that does not allow for variation in output and compression ratio cannot serve as a criterion. We must make use of the two important and controllable variables in combustion-chamber design, which are: position of maximum flame-front area, and actual flame-front area. When we do this, we establish real criteria.

We can never afford to lose sight of the fact that the shock that makes for roughness will be worse as the engine parts approach top dead-center for any given engine structure. Since the dead-center location from the point of ignition is controlled by spark advance, we are forced to make correction for the one pre-known factor that affects spark advance; that is, compression ratio.

Fig. 6 is a chamber analysis that gives us a good idea of what *NOT* to do. This chamber is a check on a new competitive model, and indicates to us that the chamber shape is the same as in previous years; yet the compression ratio has been materially raised. This chamber will require a lot of rubber in the mountings, or the spark will be much retarded.

Fig. 7 is thrown in for good measure for those chappies that can quickly sum up ten years of work in a few seconds with: "IT'S NO GOOD!—IT WON'T WORK!"

Fig. 7—Just a Happy Ending

Variation in Flame Velocity During the Burn Discussed

—Robert N. Janeway
Engineering Division, Chrysler Corp.

I AM grateful to Mr. Minter for his emphasis in this paper on the principle of volume distribution as the only means of control of combustion roughness. Not since Alex Taub made his masterly summary of the writings of Ricardo, Whatmough, and myself, has there been any other published recognition of this fundamental truth. Certainly, it will bear repetition if it is ever to achieve general acceptance among the engineering fraternity.

Mr. Minter's paper proves him to be a keen student of this subject, although his point of view is unfortunately more academic than practical. It is evident that he lacks first-hand experimental contact with the problem from his attempt in this paper to develop a completely rational quantitative method for predicting the pressure-time characteristic of combustion.

The obstacles to this achievement, which defy even Mr. Minter's ingenuity as a mathematical analyst, are inherent in the lack of conclusive quantitative knowledge of the laws of flame propagation.

One of the most vital factors in the prediction of the combustion characteristic is the nature of the variation in flame velocity during the burn. From what seems to have been rather superficial study of available experimental data on this subject, Mr. Minter concludes that flame velocity starts from zero, reaches a maximum when one-half of the chamber volume has been flame-swept, and falls to zero at the end of the flame travel.

As a matter of fact, there is very little basis for any of these assumptions in the references cited by Mr. Minter. In the first place, the initial velocity cannot be zero, or combustion would never get under way. Certainly, there is no reason to expect the flame velocity to fall to zero at the end of its travel, nor do any of the flame photographs referred to show this to occur.

As to the maximum velocity, Mr. Minter has again generalized from insufficient evidence. It is true that the photographs of Withrow and Boyd show the maximum flame velocity occurring at about 50 to 60 per cent of the extreme flame travel. However, examination of the chamber used, which was triangular both in longitudinal section and plan view, shows that this point corresponds to more nearly 80 than 50 per cent of swept volume. Moreover, the velocity does not decrease continuously thereafter, but in most cases remains constant at some lower value than the maximum or even accelerates again.

It is unfortunate that so much of available flame-propagation data is of doubtful practical value, because of the tendency to adapt the chamber shape to the particular experiment, instead of adapting the experiment to a particular chamber. I believe that the wide range of bastard chamber designs represented in such experiments is responsible for the confused picture they present as to flame-velocity characteristic. A notable exception is to be found in the work of Marvin, also cited by Mr. Minter, who included in his investigation a dome-type offset-head of the type now in general use on L-head engines.

In this case, the flame velocity is shown to increase gradually throughout the main chamber, and to continue at almost the maximum value throughout the narrow clearance space. The average maximum velocity, taken over the entire flame front, was less than twice the initial velocity. In reality, this is in fairly close agreement with the relationship used by me; namely, that flame velocity is proportional approximately to the square root of pressure, during combustion in the main portion of the chamber.

Although I did not have the benefit of flame-velocity measurements when this relationship was established a number of years ago, neither was I confronted with the wide variation in results which would have surely led me to despair of ever formulating a method of prediction. Faced by the same confusion, Mr. Minter, with rare courage, compromises on a simple equation which disregards practically all of the experimental data.

Having practically no choice but to combine the empirical with the rational method of solution, I was forced to establish the values of constants in my equations by "cut and try," until the calculated pressure-time characteristic for a given chamber agreed closely with the indicator card obtained in actual operation on the engine.

This is the only method of attack which can be logically justified, considering the complexity of the subject. In no other way can we acknowledge the fact that certain assumptions of unknown accuracy are involved in any rational approach to this problem. For instance, we know that the assumption of regular spherical flame front is at best only approximate; then, there are the uncertain characteristics of compression of the burned and unburned gas during combustion. However, by resorting to empirical quantitative values based on actual pressure-time characteristics, the errors in assumption are to a great extent atoned for.

On the other hand, to derive a complete quantitative formula entirely by dogmatic assumption, as Mr. Minter has done, inevitably leads to a false result. The obviously distorted pressure-time curve of Fig. 8 in Mr. Minter's paper, is the best proof that the sin of the assumption is visited upon the mathematical offspring.

Interpretation of the pressure-time characteristic in terms of roughness is fully as important as an accurate method of predicting the characteristic in the practical realization of smooth combustion. Pre-determination of the characteristic is obviously futile unless it aims at a sound ideal. In this connection, Mr. Minter misses the point of his own illustration in Fig. 1, when he states vaguely "that roughness is due to a very rapid increase in pressure at some stage of the burning."

Referring to Fig. 1, two pressure-time indicator-cards are shown obtained, respectively, from a smooth and from a rough engine. The total burning time and maximum rate of pressure rise are about the same in both cases. The only outstanding point of difference is in the acceleration in rate of pressure rise, the rough combustion attaining its maximum rate in one-third the time required by the smooth combustion.

Most investigators, including Ricardo, have supposed that roughness is governed only by the maximum rate of pressure rise. I too began the investigation of this subject under the delusion that roughness was a matter of the maximum rate of pressure rise. I was cured of this by designing chambers which could not be rough, on the basis of maximum rate of pressure rise; but which, nevertheless, were rough. Examination of indicator-cards in those cases showed that, while the maximum rate of pressure rise was innocently low, the maxi-

mum acceleration in the rate of pressure rise was suspiciously high. Working backward, I was forced finally to consider the actual mechanism of roughness. The answer then became clear: roughness is due to shock which gives rise to excessive deflection of the pressure-loaded engine-members. The excessive deflection is due to the inertia of the deflecting mass, which prevents the deflection from keeping pace with the pressure when the latter rises at a rapidly accelerated rate. Strictly speaking, the shock factor is an integrated effect of the entire pressure-time characteristic, in which the maximum rate of pressure rise is a factor, but the maximum acceleration in the rate of pressure rise is of predominating importance. Detailed proof of this theorem was given by me in a paper on combustion-chamber design, published in the S.A.E. JOURNAL in May, 1929.

I am at a loss to account for Mr. Minter's insistence on the dependence of combustion time on combustion-chamber volume, particularly because this view is so inconsistent with the rest of his paper. Since it is recognized that flame spreads substantially uniformly in all directions from the point of ignition, it is obvious that the range of volume which can be traversed by flame in a given length of travel is limited only to that of a sphere of radius equal to travel. Thus, the time required to burn a charge confined in a segment of a sphere would be no greater than that required in a chamber which included a complete sphere. Furthermore, it is fundamental to the principle of volume distribution as a means of control, that the burning must take place at the same rate over the entire flame front.

Certainly, the fact that burning time is reduced by increasing compression ratio can be accounted for entirely on the basis of higher charge pressure and temperature during combustion, and reduced exhaust gas dilution of the charge.

Without wishing to appear harsh or ungracious with Mr. Minter, I have tried to stress the importance of accuracy both in prediction of combustion characteristic and in its interpretation in terms of roughness as the only reliable means of achieving engine smoothness by combustion-chamber design. This is not a matter of academic hair-splitting. The number of possible combinations of chamber shape and spark plug position is infinite. It would have been practically hopeless to obtain anything like optimum smoothness by the "hit-and-miss" method. Likewise, one major error in assumption would be fatal to an entirely rational solution, such as Mr. Minter has attempted.

Having once established the required variation in swept volume with flame travel, this characteristic can be used as a criterion for further combustion-chamber designs. Alex Taub, in his present discussion, has shown how advantage can be taken of the existence of such a criterion to develop a reliable method of combustion-chamber design. Mr. Taub is to be congratulated on the thoroughness and intelligence with which he has applied the principle of volume distribution to pre-determine smooth combustion.

Rubber Body Parts

THERE are many rubber body parts. Among these are all the window insulations, bumpers, air seals, door stops, matting and cushions. In my opinion, insufficient attention has been paid to the insulation between the body and chassis frame. There are only two ways I can see that this connection should be made. Either a perfectly solid connection should be made, in which case no rubber will be required, or if it is insulated it should be well insulated with a design to absorb small vibrations, take up variations in manufacturing tolerances and, on the other hand, be rigid enough to prevent any horizontal movement.

Many experiments are being carried on in combinations of rubber materials or rubberized materials for seat cushions, arm rests or panel insulation. In England sponge rubber seat cushions of certain designs are commonly used. We have experimented in the United States with similar cushions of a possibly improved design, but have not been able to reduce their weight successfully down to that of the present spring cushions. This has been one of the most severe handicaps in the progress of this material, as probably the price and the performance are equal, in the face of advantages still inherent in the steel spring cushion.

It is possible that a combination of sponge rubber and rubberized spun hair will make satisfactory seats and help somewhat in the reduction in weight. It also seems possible to me that decided improvements could be made in the stability of the spun hair cushions to make an acceptable production item for the body manufacturers.

Inside the bodies many more parts could be made out of hard rubber, as the color combinations and finishes obtainable in this product make it suitable for obtaining the desired appearance. We have steering wheels in various designs but I am sure that the appearance could be improved further to harmonize with the trimming finish. Hard-rubber-covered door handles have practically disappeared from cars. In this instance, cost was the deciding factor.

Running boards are very important automobile parts which might be classed under the body parts. They not only prevent slippage in getting in and out of the car but they have many other features that do not seem to be apparent at first thought. A rubber-covered running board is a big factor in eliminating road noises, preventing the finish of the car from being scratched, or acting as a gravel deflector, and is also a decided improvement to the appearance of the car. It lengthens the lines of the body and puts a finishing touch on the entire appearance of the automobile between the body and the ground. Possibilities of further improving the design of this vital part on the automobile are many. The color combinations might be worked out to harmonize better with the body or the trimming of the body. Metal inserts might be used to break the long lines if so desired.

Just as important as running boards, as far as road noise elimination is concerned, are fender liners. I believe that on the higher priced car this item will have to be included as a standard necessity. It might be made out of a sheet of rubber applied on the under side of the fender or might be in the form of a cement which is painted on in a heavy coat. This not only eliminates noise but it prevents the fenders from being dented by flying gravel.

Excerpt from paper entitled "Engineering Uses of Rubber" presented at the Annual Meeting, Detroit, Jan. 14, 1935, by Curt Saurer, Firestone Tire and Rubber Co.

"The information and association provided through S.A.E. membership are

Essential To Success

of both young and experienced engineers",

Says:

E. A. Johnston

MR. Johnston is vice-president and director of engineering for the International Harvester Co. His view of S.A.E. membership is particularly interesting as it incorporates the talents of an engineer and executive in a company whose products are found in nearly every field.

Mr. Johnston has been a member of the Society since 1918. Thirty-six other engineers and executives of the International Harvester Co., in the United States and Canada, are also members of the S.A.E.

THIS PAGE IS SPONSORED FOR THE INSPIRATION OF OUR PRESENT MEMBERS—FOR PRESENTATION TO PROSPECTIVE MEMBERS—BY

THE SOCIETY OF AUTOMOTIVE ENGINEERS, INC.

29 West 39th Street, New York

What Members Are Doing

S. A. Jeffries has been named chief engineer of the Stutz Motor Car Co., Indianapolis. He was formerly commercial-car engineer for the Reo Motor Car Co.

Edward Spurr, who has been doing experimental work for Scott Paine, famous British pilot, has resigned to devote all his time to research work in connection with high-speed racing craft.

Richard Dalton, formerly inspector with the Wright Aeronautical Corp., Paterson, N. J., is now in the sales department of the Divine Bros. Co., Utica, N. Y.

John P. Hervey is connected temporarily with the Johnson Foundation for Medical Physics, at the Hospital of the University of Pennsylvania, Philadelphia.

Dr. B. J. Lemon, who in the past has represented the United States Rubber Co. at Detroit, as field engineer to contact car manufacturers, has been transferred to the company's headquarters in New York.

Last Summer, Dr. Lemon had charge of the company's exhibit in the Ford Exposition Building at the Century of Progress in Chicago. The transfer to New York was made to enable him to do special work in cooperation with the New York office of the U. S. Rubber Co.

John P. Callahan, formerly draftsman with the Chance Vought Corp., is now teacher of industrial processes at the Brooklyn Technical High School, Brooklyn, New York.

Roger W. Angstman is connected with the McAleer Mfg. Co., Detroit, as heater engineer, but is continuing as president of the Roger Angstman Co. for sales engineering of automotive products.

Theodore P. Thomas, formerly with the Puget Sound Power & Light Co. at Wenatchee, Wash., has joined the Jackson Motor Car Co., Salt Lake City, as service manager.

Edward J. Partington is doing design and layout work for the Bendix-Stromberg Carburetor Co., South Bend, Ind. Formerly he was aeronautical engineer with the Kreider Reisner Aircraft Co., Hagerstown, Md.

James B. Rather, in charge of the general laboratories, Socony-Vacuum Oil Co., has been elected a member of the executive committee of the Society of Chemical Industry for 1935-1936.

Gustav Egloff, director of research, Universal Oil Products Co., Chicago, continues as a member of the executive committee of the S.C.I.

John F. Creamer, president and general manager of Wheels, Inc., New York, has been made second vice-president of the national Code Authority for the Wholesale Automotive Trade.

Theodore M. Robie, formerly in charge of the engineering and service department of Fairbanks, Morse & Company's branch at Dallas, has been transferred to the home office of the company in Chicago to handle its Diesel-engine resale business.

Captain Richard W. Johnson has been transferred from the Holabird Quartermaster Depot, Baltimore, to the 39th Motor Transport Company, Corozal, Canal Zone.

J. Edward Schipper, principal in Schipper Associates, has moved his office to 1235 Lafayette Bldg., Detroit.

John P. Hobart, Jr., has been named assistant chief engineer of the Hammond Machinery Builders, Kalamazoo, Mich.

Melville R. Potter, formerly service engineer with the Davis Cadillac Co., Scranton, Pa., has been named manager of service for the Cadillac Co. of Harrisburg, Harrisburg, Pa.

Victor R. Ellison, formerly a designer with the General Aviation Mfg. Corp., Dundalk, Md., is now connected with the engineering department of the International Harvester Co., at Fort Wayne, Ind.

Stephen F. Briggs, president of the Briggs & Stratton Corp., has moved his headquarters from Milwaukee to the corporation's office in Detroit.

Marcel See, formerly with the Société Anonyme Française d'Automobiles, is now connected with the Société Finançiere pour l'Automobile (S.O.F.I.A.) at Boulogne-Billancourt (Seine), France.

J. R. Akerman is an instructor in the Georgia School of Technology, Atlanta.

Capt. John R. Hubbard, previously on duty in the Procurement Branch (Motor and Water Transportation) office of the Quartermaster General, U. S. A., is now technical supervisor of all Army transportation in the Second Corps Area, with headquarters at Governor's Island, New York City.

Frank A. Best has been named president of the Backstay Standard Co., Ltd., Windsor, Ont. The company represents a consolidation of the Canadian businesses of the Backstay Welt Co., for which Mr. Best was Canadian manager, and of the Standard Products Co.

Erwin Graham has joined the Burgess Battery Co. at Madison, Wis.

Glenn L. Martin, president, Glenn L. Martin Co., Baltimore; *E. E. Wilson,* president, Chance Vought Corp., East Hartford, Conn.; and *Sherman M. Fairchild,* president, Fairchild Aviation Corp., Hagerstown, Md., were elected vice-presidents and directors of the Manufacturers Aircraft Association, Inc., at the annual meeting of the association on Feb. 28. *C. J. Brukner,* president, Waco Aircraft Co., Troy, Ohio, was elected a director and treasurer of the organization.

Arthur J. Aiers is now works superintendent for the British Oxygen Co., Edmonton, London, England. Recently he has been costs investigator for the Triumph Motor Car Co., Ltd., Coventry, England.

Russell T. Howe, formerly engineer with the Ray Day Piston Corp., Detroit, is now engineer on spark plugs, batteries and brake lining at the Los Angeles plant of the Firestone Tire & Rubber Co.

E. M. Schultheis, automotive engineer for the Timken Roller Bearing Co. for the past eight years, has been appointed district manager of sales in the company's automotive division at Detroit.

Walter C. Becker, formerly automotive engineer with the Chicago Surface Lines, has become chief product engineer for the Ohio Brass Co., Mansfield, Ohio.

John C. Estabrooke is connected with the automotive purchasing department of R. H. Macy & Co., New York City.

William Jack, formerly chief engineer, acoustic division, Burgess Battery Co., has joined the research staff of Johns-Manville, Inc., at Manville, N. J.

Richard B. Sargent, formerly automotive engineer with the Sun Oil Co. at Pittsburgh, has joined the Hale Fire Pump Co. at Conshohocken, Pa.

C. F. Hood, former assistant manager in the Worcester, Mass., district for the American Steel & Wire Co., has been transferred to the Cleveland office of the company.

E. D. Herrick is now executive engineer for the Lycoming Mfg. Co., Williamsport, Pa.

Fred Crawford Thompson

Fred Crawford Thompson, age 51, vice-president and general manager, Morse Chain Co., a subsidiary of the Borg-Warner Corp., died

F. C. Thompson

March 6. Mr. Thompson has been identified with the automotive industry for 32 years and was recognized as one of its pioneers and leaders.

Born in Emlenton, Pa., in 1884, he started his career as a draftsman with Westinghouse Electric. Later he was associated with Pope-Toledo Co., as a designing engineer. He was also connected with Fairbanks Morse & Co. and the Buda Co., and in the early days of the automotive industry was chief engineer of the

Lozier Motor Co. In 1914, he joined the Morse Chain Co. as Detroit manager, and during the last five years had been vice-president and general manager of the company. Many of his inventions are now being used by the automotive industry.

Mr. Thompson was a member of the Society of Automotive Engineers since 1915; other affiliations included the Bloomfield Hills Country Club; Detroit Athletic Club; Ithaca, N. Y., Country Club, Ithaca Chamber of Commerce and Westminster Presbyterian Church at Ithaca.

Charles Walker Gibford

Charles W. Gibford, of Adrian, Mich., formerly connected with the Twin Flex Corp., Detroit, died Feb. 10, 1935.

Captain John Beveridge, Jr.

Capt. John Beveridge, Jr., Air Corps, U.S.A., a service member of the Society since 1921, died Feb. 1 after a prolonged illness. He had been attached to Maxwell Field, Montgomery, Ala., but was sent to Walter Reed Hospital in Washington, several months ago for treatment.

Amendments to Constitution

Constitutional and By-Law Amendments Adopted

To the Members:

The amendments to the Constitution of the Society set forth in the letter ballot dated January 31, 1935, have been adopted.

These amendments related to paragraphs 15, 22, 45, 46, 50A, 54 and 57 of the Constitution of the Society. The report of the Tellers follows:

March 4, 1935

Total votes cast 548
Ballots defective 5

	Ballots favoring adoption of proposed amendments	Ballots not favoring adoption of proposed amendments
C-15	520	23
C-22	530	13
C-45	525	16
C-46	528	15
C-50A	530	13
C-54	529	12
C-57	525	17

Tellers: E. R. Gurney
M. C. Horine
E. C. Blackman

The above amendments, which are now in effect, were printed in full in the November, 1934, issue of the S.A.E. Journal (pp. 31 and 32).

Amendment to By-Laws Adopted

At the April 25, 1934, Council meeting an amendment to B-26 was approved and it was directed that this amendment was to become effective when the amendment to C-46 was adopted.

As noted above, the amendment to C-46 has been adopted, therefore the following amendment to B-26 is now in effect:

Amendment to B-26—Nominating Committee

The first paragraph to be replaced by the following:

"It shall be the duty of the Annual Nominating Committee to organize at the Annual Meeting of the Society. The delegate at large of longest membership in the Society who is present shall act as temporary Chairman. The Secretary of the Society shall supply the temporary Chairman with a list of delegates and alternates elected to serve on the Committee. The first duty shall be to examine the credentials of the delegates and alternates and seat the representatives for the various Sections in accordance with the provisions of C-46. The representation of a Section, after a representative is once seated, shall not be changed during any session of the Nominating Committee. The Committee shall send to the Secretary of the Society, subsequent to the Semi-Annual Meeting and prior to September 15, the names of consenting nominees for the elective offices next falling vacant under the Constitution, except the Vice-Presidencies representing the Professional Activities. This report shall be signed by the Committee Members present at the meeting. The report of the committee shall be printed in the next current publication of the Society subsequent to its receipt by the Secretary."

Remaining two paragraphs of B-26 to be as at present.

Society of Automotive Engineers, Inc.,
John A. C. Warner, Secretary

Proposed Constitutional Amendment

To the Members:

At the Business Session of the Annual Meeting of the Society held in Detroit, Mich., in January, 1935, the amendment to the Constitution set forth below was presented:

In compliance with the Constitution the proposed amendment is submitted herewith to the voting members of the Society for their consideration prior to the 1935 Semi-Annual Meeting. After discussion and final amendment at the latter meeting, the amendment will be submitted by letter ballot to all members entitled to vote, provided 20 votes in favor of such submission are cast at that meeting.

Proposed Paragraph to be added to the Constitution:

C-24A. Past Presidents of the Society shall be admitted to Life Membership without payment of a life membership fee at the end of their second year's service on the Council as Past Presidents.

Society of Automotive Engineers, Inc.
John A. C. Warner, Secretary

New Members Qualified

These applicants who have qualified for admission to the Society have been welcomed into membership between Feb. 10, 1935, and Mar. 10, 1935.

The various grades of membership are indicated by: (M) Member; (A) Associate Member; (J) Junior; (Aff.) Affiliate Member; (SM) Service Member; (FM) Foreign Member.

AYERS, KENNETH A. (A) lubricating engineer, Standard Oil Co. of California, Pacific Building, Portland, Ore.; (mail) 5010 North East 35th Avenue.

BELINN, CLARENCE M. (M) superintendent of maintenance, National Airways, Inc., Boston Municipal Airport, Boston.

BURLEW, FRED NORTHROP (J) assistant, stress analysis department, Curtiss Aeroplane & Motor Co., Inc., Buffalo, N. Y.; (mail) 870 LaFayette Avenue.

COYLE, JOSEPH L. (A) owner, 22 Stoneleigh Circle, Watertown, Mass.

CRAIG, ROBERT S. (J) 41 Roosevelt Road, Maplewood, N. J.

DANNEMANN, HENRY F., 2nd (J) junior engineer, motor test laboratory, Tidewater Oil Co., East 22nd Street, Bayonne, N. J.; (mail) 453 West 155th Street, New York City.

DELONG, LUTHER A. (A) service manager, Topton Motor Co., Corner Weiss Street and Home Avenue, Topton, Pa.

DURBIN, JOHN B. (A) sales representative, General Motors Truck Co., 1775 Broadway, New York City.

GREENSHIELDS, R. J. (J) junior engineer, motor testing laboratory, Shell Petroleum Corp., Wood River, Ill.; (mail) 623 Whitelaw Avenue.

HAYES, CECIL (F M) development engineer, Automotive Products Co., Ltd., Leamington Spa, England.

KENNEDY, MAURICE DEKAY THOMPSON (J) student engineer, Buick Motor Co., Flint, Mich.; (mail) 2119 Imperial Court.

KEOWN, G. W. (A) commercial engineer, Westinghouse Lamp Co., Bloomfield, N. J.

KIRKWOOD, GEORGE M. (M) superintendent, Pennsylvania Refining Co., Karns City, Pa.

KUDLICH, DONALD (J) observer, Wright Aeronautical Corp., Paterson, N. J.; (mail) 20 West Holly Street, Cranford, N. J.

KURGANOFF, ALEXIS IVANOVICH (F M) engineer, Plant Stalin's Name, Leninscaja Slobada, Moscow, U.S.S.R.; (mail) St. of Machinastroenija 4, Kv. 50, Moscow 88, U.S.S.R.

LEVINE, DANIEL M. (J) engineer, Federal Engineering Co., 2519 Bellevue, Detroit.

MILBURN, LESSITER CRARY (M) chief engineer, Glenn L. Martin Co., Baltimore, Md.

MORI, TARO (F M) designer, Tokyo Gas & Electrical Engrg. Co., Ltd., Tokyo, Japan; (mail) 731, 2-Chome, Shimoochiai, Yodobashi-Ku.

MYERS, CARLTON M. (A) automotive engineer, Socony-Vacuum Oil Co., Inc., Albany, N. Y.; (mail) 20 Harris Avenue.

NELSON, CHARLES PHILLIP (A) fleet manager, Edgemar Farms, 346 Rose Avenue, Venice, Calif.; (mail) 1918-19th Street, Santa Monica, Calif.

OLIVER, FRANK J. (M) industrial coordinator, University of Detroit, College of Engineering, McNichols Road and Livernois, Detroit.

PATCHETT, GEORGE WILLIAM (M) chief designer, Zbrojovska Ing. F., Janecek, Praha, Nusle 2, C.S.R., Czechoslovakia; (mail) U. Druhe Baterie c10, Stresovice c764, Prague 18, Czechoslovakia.

POTTER, RAYMOND I. (J) sales engineer, charge of motor analysis work, Standard Oil Co. of Ohio, 16th Floor, Midland Building, Cleveland; (mail) 1356 Cranford Avenue, Lakewood, Ohio.

ROSEN, HAROLD (A) senior partner, American Grease Stick Co., Muskegon, Mich.

RYDER, KENNETH F. (J) engineer, transportation department, Panama Canal, Canal Zone; (mail) Box 97, Balboa Heights, Canal Zone.

TIEDEMANN, CARL (J) engineer, Chance Vought Aircraft Corp., East Hartford, Conn.; (mail) 2647 Reese Avenue, Evanston, Ill.

VALANCE, EDWARD L. (M) assistant general manager, charge of sales, Houde Engineering Corp., 537 East Delavan Avenue, Buffalo, N. Y.

WOLFSOHN, ROBERT SMITH (J) 517 West 113th Street, New York City.

YOUNG, THOS. ALEX. CRAWFORD (F M) equipment manager, Irish Shell, Ltd., 21 Dame Street, Dublin, Ireland.

Applications Received

The applications for membership received between Feb. 15, 1935, and Mar. 15, 1935, are listed herewith. The members of the Society are urged to send any pertinent information with regard to those listed which the Council should have for consideration prior to their election. It is requested that such communications from members be sent promptly.

AMOS, JAMES MORSE, assistant superintendent of transportation, Overnight Motor Transportation Co., Baltimore, Md.

ANDERSSEN, FRITHJOF, sales manager, Aktieselskabet Bil, Trondhjem, Norway.

ATKINS, NORMAN D., regional manager, General Motors Fleet Sales Corp., St. Louis, Mo.

CAMPBELL, WALTER R., salesman, New York Nu-Enamel Co., New York City.

CLARK, EDWIN JOSEPH, service manager, Sanderson & Holmes, Ltd., Derby, England.

CROUSE, R. M., secretary-treasurer, Warner-Fruehauf Trailer Co., Inc., Baltimore, Md.

DAVIS, GARLAND H. B., assistant director of Esso Laboratory, Standard Oil Development Co., Elizabeth, N. J.

DOERR, CHARLES SCHUYLER, shop superintendent, The Atlantic Refining Co., Philadelphia.

ENSINGER, WILLIS B., junior mechanical engineer, U. S. Navy Department, Washington, D. C.

GULOWSEN, KNUTE M., teacher of auto mech., Board of Education, City of New York, New York City.

HALL, WALTER, vocational drafting instructor, John C. Fremong High School, Los Angeles, Cal.

HAUSHALTER, FRED L., development engineer, B. F. Goodrich Co., Akron, O.

HEINTZE, ARTHUR L., staff engineer, Sinclair Refining Co., New York City.

HERRICK, JAMES, service manager, H. O. Penn Machinery Co., New York City.

HOPKINS, BEN F., president, The Cleveland Graphite Bronze Co., Cleveland.

ILSLEY, KARL A., 9 Methuen St., Lowell, Mass.

LOCHNER, FRED, maintenance manager, Pulaski Trucking Corp., Brooklyn, N. Y.

MCGREGOR, DAVID LAURIE, shop foreman, Hal Hillman Motors, Portland, Oregon.

MCMAHON, LEONARD H., manager, lubricating oil department, The American Oil Co., New York City.

MELHUISH, MAURICE, director, Glacier Metal Co., Ltd., Alperton, Middlesex, England.

MORFE, JOSEPH D., superintendent of maintenance, Overnight Motor Transportation Co., Baltimore, Md.

MORROW, JAMES G., chief metallurgist, The Steel Co. of Canada Ltd., Hamilton, Ont., Canada.

POULIN, JOSEPH, president, Asbestonos Corp., Montreal, Que., Canada.

PULEO, JAMES, chief mechanic, Bleecker Auto Repairs, Brooklyn, N. Y.

SANDERS, ARTHUR FREEMAN, engineer in charge engineering department, John Fowler & Co., Ltd., Leeds, England.

SCHWARTZ, IRVING W., general manager, Zone Oil Trucking Corp., Brooklyn, N. Y.

SIERS, THOMAS WILLIAM, maintenance manager, Airways Building, Winnipeg, Man., Canada.

SPATTA, GEORGE, Clark Equipment Co., Buchanan, Mich.

ROSENBERGER, R. J., assistant superintendent, Pennoyer Merchants Transfer Co., Chicago.

WACKETT, COM. LAWRENCE JAMES, consulting aeronautical engineer, Tugan Aircraft Co., Sydney, Australia.

WALTON, G. M., vice-president, engineering, Air-Maze Corp., Cleveland.

WARD, JOHN T., director of research, M. W. Kellogg Co., New York City.

WOMACK, RICH, service manager, Ross Motor Co., Multnomah, Ore.

YOST, GEORGE W., general manager, Suburban Transportation System and Tricoach Corp., Seattle, Wash.

THE WORD-HUNT IS OVER!

THE TROPHY

"Bundyweld Tubing for Durability—and Dependability," said the Bundyweld ads.

"We need a third word beginning with D," a Bundy executive suggested. "Why not ask Bundyweld users to supply that word?" Thus was born the Bundy Word-Hunt.

Entry blanks were mailed throughout the country to 400 users of Bundyweld tubing. A $50 prize and a special trophy were offered for the best word submitted. "The winning word must begin with D; it must describe YOUR conception of Bundyweld Tubing." These were the only restrictions . . . the word-hunt was on!

Responses came in from 125 people; 165 *different* words were suggested—all of them good. After much deliberation, the judges chose the word "DIVERSABILITY".

The trophy and a $50 check goes to Mr. Carl J. Snyder of Chrysler Motors Corporation. Congratulations, Mr. Snyder! And many thanks to the other contributors for their excellent recommendations.

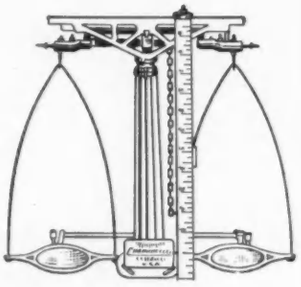
The Word-Hunt is over . . . The word DIVERSABILITY now joins DURABILITY and DEPENDABILITY to describe what every engineer and executive expects—*and gets*—when he specifies Bundyweld Tubing.

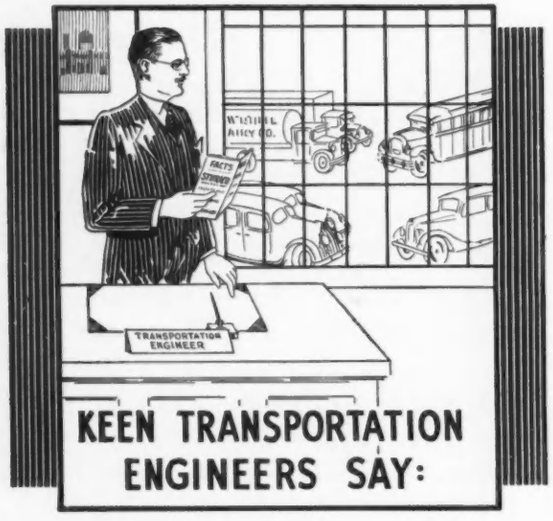
BUNDY TUBING COMPANY
10951 Hern Avenue, Detroit, Michigan

BUNDYWELD Tubing
for
Durability - Dependability
and DIVERSABILITY

"STURACO"
★★★★
EXTREME PRESSURE ("E.P.")
GEAR AND CHASSIS LUBRICANTS

BALANCE
RESEARCH
WITH
PRACTICAL
PERFORMANCE





KEEN TRANSPORTATION ENGINEERS SAY:

"Where 'EP' lubricants are required there is no choice in regard to whether or not they are used."

★ ★ ★ ★

"Where 'EP' lubricants are not absolutely required they may still be desirable on account of their greater factor of safety . . ."

"STURACO" E. P. LUBRICANTS
ARE THE ORIGINAL DEVELOPMENT OF
D. A. STUART & CO.
ESTABLISHED 1865
GENERAL OFFICES: 2727-2753 SO. TROY ST. CHICAGO, U.S.A.
BRANCHES IN PRINCIPAL CITIES

Notes and Reviews

THESE items, which are prepared by the Research Department, give brief descriptions of technical books and articles on automotive subjects. As a rule no attempt is made to give an exhaustive review, the purpose being to indicate what of special interest to the automotive industry has been published.

The letters and numbers in brackets following the titles classify the articles into the following divisions and subdivisions: *Divisions*—A, Aircraft; B, Body; C, Chassis Parts; D, Education; E, Engines; F, Highways; G. Material; H, Miscellaneous; I, Motorboat; J, Motorcoach; K, Motor-Truck; L, Passenger Car; M, Tractor. *Subdivisions*—1, Design and Research; 2, Maintenance and Service; 3, Miscellaneous; 4, Operation; 5, Production; 6, Sales.

AIRCRAFT

Twentieth Annual Report of the National Advisory Committee for Aeronautics, 1934

Administrative Report Without Technical Reports; 42 pp. Price, 15 cents. [A-1]

Air Conditions Close to the Ground and the Effect on Airplane Landings

By F. L. Thompson, W. C. Peck and A. P. Beard. N.A.C.A. Report No. 489, 1934; 15 pp., with tables and charts. Price 10 cents. [A-1]

A Flight Investigation of the Lateral Control Characteristics of Short Wide Ailerons and Various Spoilers with Different Amounts of Wing Dihedral

By Fred E. Weick, Hartley A. Soulé, and Melvin N. Gough. N.A.C.A. Report No. 494, 1934; 16 pp., with tables and charts. Price 10 cents. [A-1]

Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack—XII-Upper-Surface Ailerons on Wings with Split Flaps

By Fred E. Weick and Carl J. Wenzinger. N.A.C.A. Report No. 499, 1934; 17 pp., with tables and charts. Price 10 cents. [A-1]

The Influence of Tip Shape on the Wing Load Distribution as Determined by Flight Tests

By Richard V. Rhode. N.A.C.A. Report No. 500, 1934; 25 pp., with tables and charts. Price 10 cents. [A-1]

Scale Effect on Clark Y Airfoil Characteristics from N.A.C.A. Full-Scale Wind-Tunnel Tests

By Abe Silverstein. N.A.C.A. Report No. 502, 1934; 15 pp., with tables and charts. Price 10 cents. [A-1]

The Effect of Spray Strips on the Take-Off Performance of a Model of a Flying-Boat Hull

By Starr Truscott. N.A.C.A. Report No. 503, 1934; 19 pp., with tables and charts. Price 10 cents. [A-1]

On the Theory of Laminar Boundary Layers Involving Separation

By Th. von Kármán and C. B. Millikan. N.A.C.A. Report No. 504, 1934; 22 pp., with tables and charts. Price 10 cents. [A-1]

A Complete Tank Test of the Hull of the Sikorsky S-40 Flying Boat—American Clipper Class

By John R. Dawson. N.A.C.A. Technical Note No. 512, December, 1934; 16 pp., 18 figs. [A-1]

The Wave Suppressors Used in the N.A.C.A. Tank

By Starr Truscott. N.A.C.A. Technical Note No. 513, December, 1934; 5 pp., 4 figs. [A-1]

Propeller Vibrations and the Effect of The Centrifugal Force

By T. Theodorsen. N.A.C.A. Technical Note No. 516, February, 1935; 13 pp., 12 figs. [A-1]

Gliding in Convection Currents

By W. Georgii. Translated from *Luftfahrtforschung*. Vol. II, No. 5, October 25, 1934. N.A.C.A. Technical Memorandum No. 761, January, 1935; 7 pp., 4 figs. [A-1]

(Continued on page 32)

THAT WONDERFUL PROGRAM owes much to the factor of control . . . to the technical engineers behind the scenes who govern the many subtle elements involved in successful transmission. Control at the source is equally important in the manufacture of open hearth carbon steels for forging, heat treating, forming and machining. Under recently developed Carnegie Control methods, grain size, working qualities and performance are governed with altogether new assurance. If you have not studied this development in relation to your steel requirements, you are missing something. Carnegie Controlled Steels are the solution of your production problem.

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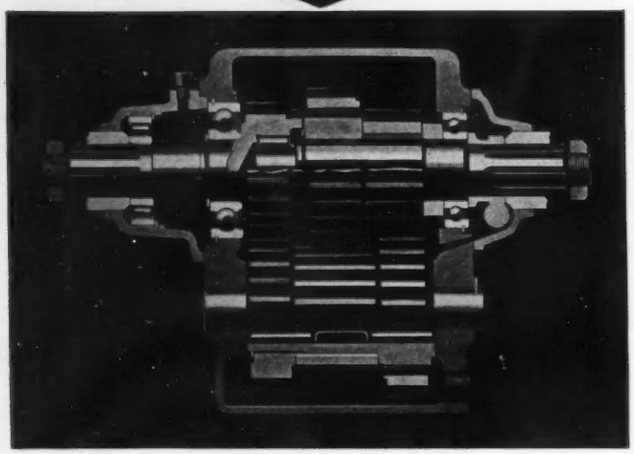
Spicer



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BROWN-LIPE 2231
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● With this Brown-Lipe Auxiliary Transmission, the bus or truck operator can always use exactly the right range, and can readily change back and forth from one to the other. This is a great advantage over other types of units whether connected with the clutch or the axle . . . With the Auxiliary Transmission, the low-low speed gives greater traction on soft ground, rough roads and steep grades. The high-high speed gives about 25% faster road speed with no increase in gas or oil consumption.

(Left)—Compact, efficient, this Brown-Lipe Auxiliary Control can be used with all 3-speed Auxiliary Transmissions.

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NOTES AND REVIEWS

Continued

MATERIAL

Alkohol-Gemisch-Kraftstoffe

Published by the Österreichisches Petroleum-Institut, Vienna, Austria. 31 pp. [G-1]

The Austrian Petroleum Institute has reviewed 139 articles to make this survey of the literature on alcohol-blended fuels. The articles are taken from the German, French and English technical press, for the most part of the last two years. They are reviewed under the headings, ethyl alcohol, alcohol and alcohol fuels, alcohol-hydrocarbon blends and their stability, production and blending, carburetion, combustion, consumption in comparison with gasoline, engine power in comparison with gasoline.

The Principles of Motor Fuel Preparation and Application—Volume I

By Alfred W. Nash and Donald A. Howes. Published by John Wiley & Sons, Inc., New York and London, 1935; 538 pp., illustrated. [G-3]

A. E. Dunstan, well known to many members of the Society, points out in his forword to this volume that the authors have presented a work on the subject of motor fuels that contains not only very complete descriptions of present day technique but includes also discussions of problems that will undoubtedly arise in the future.

Alfred W. Nash is Professor of Petroleum Technology, University of Birmingham and Vice-President of the Institution of Petroleum Technologists; Donald A. Howes is associated with the Anglo-Persian Oil Co., Ltd.

Volume I deals with the production of motor fuels by methods of distillation, cracking, extraction from natural gas and hydrogenation. It also contains chapters concerning the production of benzole, various synthetic fuels, including alcohols, and general storage and distribution.

Volume II is expected shortly.

MISCELLANEOUS

Industrial Standardization Especially in the Mechanical Field

By John Gaillard. 123 pp.; 9 illustrations. [H-1]

Standardization is, in this book, led from its customary prosaic abode of unadulterated fact and concrete measurement into the realm of philosophy. An attempt is made to expound a science of standardization, based on the developments of the past and on a general consideration of factors, human, social, economic and commercial, affecting standardization. In the course of the analysis, guiding principles of future standardization are indicated.

The numerous and apt factual references indicate the author's familiarity with his subject gained from his long years of notable service on the staff of the American Standards Association. Many of these references are to events and developments in the automotive industry.

Some of the subjects dealt with are the evolution of standardization, its essential functions, definitions and characteristics of a standard, the practical application of standardization and the technique of standardization in individual organizations.

Standard Gear Book

By Reginald Trautschold. Published by McGraw-Hill Book Co., New York and London, 1935; 314 pp. [H-3]

The purpose of this book, as stated by the author, is to supply the facts behind the important advances in commercial gear-production practices during the past quarter century, to reiterate the basic principles upon which the operation of the modern gear-generating machines and the art of gear designing are founded, and to show how and why transmission efficiencies of 99 per cent plus have been attained.

Mr. Trautschold refers to the early work of Charles H. Logue, "American Machinist Gear Book," revised in 1915 and again in 1922, and explains that changing industrial conditions indicated the need for a book of somewhat different character, a practical treatise on gearing presented simply, clearly and in a manner helpful to the builder of gear production equipment, the gear designer, and the commercial user of gears, rather than an orthodox fourth edition of the Logue work.

La Fonderie de Fonte dans l'Automobile

By François Thivot. Published in *Journal de la Société des Ingénieurs de l'Automobile*, December, 1934, p. 2995. [H-5]

The author, one of the foremost experts in foundry practice in France, treats of foundry operating practice and materials as applied to cylinder blocks, valve seats, cylinder heads, cylinder liners, camshafts, crankshafts, brake drums and exhaust piping.

(Continued on page 34)

ANOTHER FORWARD STEP
in the Lubrication Field
by ALEMITE

THE new 1935 Alemite Lubricating Equipment is evidence of still another forward step in the automotive lubrication field . . . and ranks in importance with the recent introduction of the new Alemite TEMPRITE Lubricants.

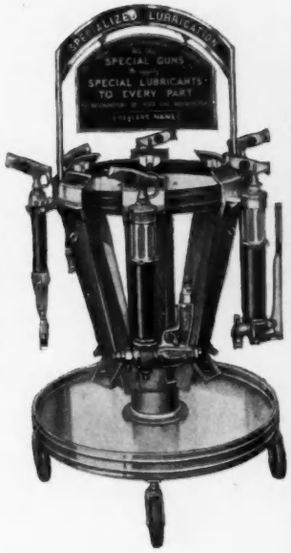
Alemite has called upon every engineering facility to produce this new 1935 line, designed to meet—in every way—the exact lubrication demands of the modern high-speed motor car.

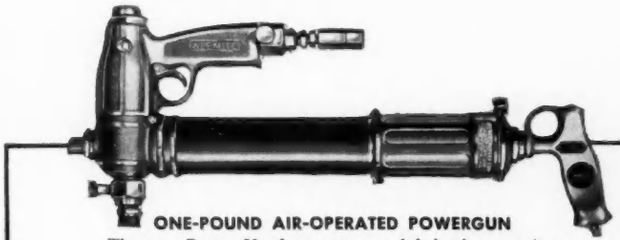
New guns—standardized units—new couplings, which eliminate scores of parts—new safety features—greater accessibility to mechanisms—simplified efficiency . . . these are only a few of the many new and time-saving features which have been built into this new equipment.

The 1935 Alemite Lubricating Equipment is the tangible result of gearing the knowledge and experience of Alemite engineers to one paramount purpose—to provide the most advanced lubrication service for today's powerful, new motor cars.

THE NEW ALEMITE "RUNABOUT"

The Alemite "Runabout" is the last word in portability. Finished in chip-proof maroon and chromium, with special dealer's display sign. Handles 3 to 9 lubricating guns, with name plates for each gun. Convenient compartments for gun adapters and two trays for small tools, oil cans and rags.





ONE-POUND AIR-OPERATED POWERGUN

The new Power Head converts any lubrication gun into a power-operated gun. It pumps both regular and fibrous lubricants, and develops pressures *13 times air pressure*. One coupling serves both Push-Type and Hydraulic fittings. Air priming permits the pumping of heavy, fibrous lubricants with ease.

25-POUND POWERGUN

A new 25-pound Powergun, operated either by air or electricity, will give fast and positive high-pressure lubrication. Equipped with the new Super-Alemite 20,000-pound-pressure hose, built-in hose rack, and silent rubber swivel casters. The trouble-free mechanism is exposed by unscrewing one bolt on cover.

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NOTES AND REVIEWS

Concluded

PASSENGER CAR

Les Tendances de la Technique Automobile Américaine d'apres le Salon de New York (5-12 Janvier 1935)

By G. Delanghe. Published in *Le Génie Civil*, Feb. 16, 1935, p. 149. [L-1]

American automotive technique has continued to show progress, but with a wary attitude toward certain radically advanced design features that are more cordially accepted in France and Germany. This is a foreigner's summation of his impressions of the New York Automobile Show. The goal of American manufacturers is said to be greater comfort, easier handling and more attractive appearance. Selected features of new models are commented on.

Eine Ausstellung der Evolution

By Wa. Ostwald. Published in *Automobiltechnische Zeitschrift*, Feb. 10, 1935, p. 51. [L-1]

To use domestic products, specifically for fuel and tires, improve riding-qualities not only of passenger cars but of motor trucks also, to bring down operating costs of all kinds and achieve increased freedom from service and repair needs—these are the lines of future progress pointed out in the leading article of the show number of this magazine.

The present state of the German automotive industry is said to be that of evolution, testing and utilizing the many new radical developments that have resulted from the recent technical revolution. Satisfactory cars of all types are said to be available among German products.

Other articles in the issue review shows of the past 35 years and enumerate the most outstanding design features of the present exhibits.

Automotive Essentials

By Ray F. Kuns. Published by *The Bruce Publishing Co.*, New York, Milwaukee and Chicago, Revised Edition, 1935; 433 pp., illustrated. [L-3]

Completely revised and rewritten edition of an automotive textbook especially designed to assist the car owner in the intelligent selection, operation and repair of automobiles and automotive equipment.

YOUNG

OIL COOLERS—HEAT EXCHANGERS

for Higher Speeds—Greater Cooling

Outstanding in this new era of speed is the new streamline train being built by American Car and Foundry Company for Gulf, Mobile and Northern Railroad. Powered with McIntosh & Seymour Diesel engines proper cooling for both oil and water is assured by Young Oil Coolers and Young Heavy Duty Radiators. Backed by many years experience in Diesel engine cooling and with most complete and modern laboratory facilities for determining resistance, heat transfer and other characteristics of cooling, Young Engineers are well qualified to handle all Diesel cooling problems involving water or oil cooling units.

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